

Environmental Conditions of Surface Soils and Biomass Prevailing in the Training Area at CFB Gagetown, New Brunswick

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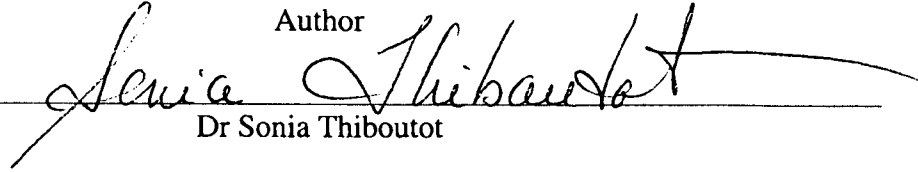
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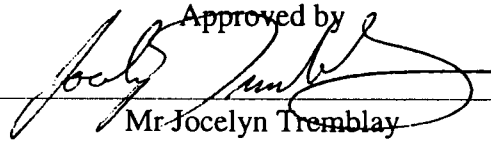
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Abstract

Troop readiness requires live fire training with various types of ammunitions. More than 99.99 % of the Canadian ammunition stockpile is used in our Country in training exercises. By better understanding the potential environmental impacts of each type of live firing activity, the Department of National Defence (DND) will be able to mitigate potential adverse effects by adapting the practices to minimize such adverse impacts. In this context, the Director Land Environment (DLE) tasked DRDC-Val to initiate a R&D program involving the environmental characterization of their main training areas to improve the knowledge on the impacts of many types of live firing training activities. DRDC-Valcartier managed the overall work and performed the surface soils and biomass studies in collaboration with Cold Regions Research and Engineering Laboratory (CRREL) scientists. The second site selected for the study was CFB Gagetown based on its intensive use by our force and allied forces and based on its geological and geographical context. In 2001, hydrogeological work was conducted in the northern half of the CFB Gagetown. This first phase involved the sampling of 42 wells to characterize the underlying groundwater flow dynamics as well as the chemical characterization of the groundwater quality. In 2002, a second phase was undertaken, including the drilling of more wells mostly in the southern half of the base and the collection of surface soils and biomass at selected locations over the entire base. This report details the surface soils and biomass characterisation of Gagetown main training ranges while a second report will be published on the hydrogeological context of the training area. Both energetic materials and metals were analysed in surface soil samples while only metals were analysed in the biomass samples. Various types of ranges were sampled including, antiarmour, antitank, grenade and rifle ranges as well as artillery impact areas. This report details the surface soils and biomass characterisation of Gagetown main training ranges. Both energetic materials and metals were analysed in surface soil samples while only metals were analysed in the biomass samples. Results obtained for metals showed the accumulation of various metal analytes in all types of ranges with higher hits in grenade and rifle ranges. Metals that showed clear accumulation pattern from the training activity were lead, strontium, cadmium, copper, zinc and aluminium. Energetic materials were detected in various soil samples in all types of ranges with the exception of the small arms ranges. The antitank range target area presented high levels of HMX and other explosives while the firing position presented detectable levels of propellant residues. Grenade ranges showed a pattern of multi-contamination by various explosives. Some hits were also recorded in the larger artillery ranges where linear composite sampling was conducted preferentially in craters. Hits were also observed near low-order events or cracked UXOs. This study was sponsored jointly by DLE and the Strategic Environmental R&D Program (SERDP) a US funding programme.

Résumé

L'entraînement militaire avec tir réel de plusieurs types de munitions est absolument nécessaire afin d'assurer que les Forces Canadiennes soient prêtes à entrer en action, que ce soit dans des missions de paix ou encore dans des conflits internationaux potentiels. La majorité de l'arsenal canadien est ainsi utilisé dans des exercices de tir dans nos secteurs d'entraînement. Recherche et Développement pour la Défense Canada- Valcartier (RDDC-Valcartier) dédie ainsi un large effort de recherche afin de supporter l'entraînement durable des forces armées canadiennes. En améliorant la compréhension des divers impacts environnementaux de l'entraînement à tirs réels, le Ministère de la Défense Nationale sera en meilleure position afin de minimiser ou d'éliminer tout effet néfaste en adaptant les pratiques de tirs. Dans ce contexte, le directeur des forces terrestres a mandaté RDDC-Valcartier afin d'initier un programme de recherche portant sur la caractérisation environnementale de leurs secteurs d'entraînement majeurs afin d'améliorer les connaissances des impacts de tous les types de tirs effectués. RDDC-Val a supervisé les travaux de recherche globaux et a effectué des études reliées aux sols de surface et à la biomasse. Le secteur d'entraînement de Gagetown a été sélectionné, dû à sa grande utilisation par les forces canadiennes et alliées ainsi qu'à sa nature géologique et géographique. En 2001, la première phase de cette étude a consisté en la caractérisation hydrogéologique partielle dans la portion nord du secteur d'entraînement. Cette première phase a impliqué le forage de 42 puits, afin de caractériser la dynamique et la qualité des eaux souterraines. En 2002, une seconde phase plus complète a été effectuée, incluant le forage de puits supplémentaires, principalement dans la portion sud du secteur et de la collecte de sols de surface et de biomasse à des endroits sélectionnés de haute intensité de tir. Ce rapport présente les résultats obtenus pour l'échantillonnage de surface. Les résultats obtenus pour les métaux démontrent une accumulation claire de nombreux analytes en relation directe avec les activités de tir avec les taux les plus élevés sont retrouvés dans les sites de grenade et de petit calibre. Les paramètres les plus souvent détectés sont le plomb, le strontium, le cadmium, le cuivre, le zinc et l'aluminium. Les matériaux énergétiques ont été détectés dans plusieurs échantillons de sol dans tous les types de site à l'exception des sites de tir de petit calibre. Des hauts niveaux de HMX et de résidus de propergols ont été détectés dans le site antitank dans la zone d'impact et de tir. Les sites de grenade démontrent un patron de multi-contamination par plusieurs composés énergétiques. Certains analytes énergétiques ont aussi été mesurés dans les secteurs d'artillerie ainsi que près de munitions non détonnées ou de munitions ayant conduit à des déflagrations. Cette étude a été subventionnée en partie par le directeur de la force terrestre ainsi que par le programme de fonds américain « Strategic Environmental R&D Program » (SERDP).

Executive summary

The international context of demilitarization, the closure of military bases and the more stringent aspects of environmental law, have led to the establishment of new areas for research and development. Many activities of the military forces such as the firing of ammunition, demolitions, and the destruction of obsolete ammunition by open burning and open detonation may lead to the dispersion of energetic compounds in the environment. It is within this context that the Defence Research & Development Canada- Valcartier (DRDC Valcartier) and Cold regions Research and Engineering Laboratory (CRREL) initiated research programs to study the environmental impact of energetic materials that are found in the Department of National Defence (DND) and the US Department of Defence (DoD) ammunition stockpile. The Program on soil characterisation positioned our departments in a state of readiness and allowed the development of a unique expertise. Moreover, the Canadian and US programs on training range research characterization positioned our departments to better understand the impacts of live fire training and therefore to be in a readiness state to answer any inquiries and take corrective actions if needed. The first training area was characterized between 1999 and 2001. It was CFB Shilo, located in Manitoba. Shilo was of interest for many reasons including the fact that 23 years of intensive training of German troops was ending. After the expertise gained in Shilo, the Director Land Forces Services (DLFS) tasked DRDC Valcartier to perform the same type of work in their major army training ranges across Canada. CFB Gagetown training area located in New-Brunswick was selected in priority for this project based on its intensive use by the Canadian Forces and allied troops and based on its particular geographical and geological context, complementary to the Shilo context. The first phase of Gagetown training area was conducted in 2001 and focused on groundwater and surface water. A first report was published on phase one and included hydrogeological and geological characterization and groundwater and surface water quality analysis. The phase two campaigns described in the present report included the follow up of the hydrogeological work and surface sampling of soils and biomass in major and representative live firing ranges. It was partly sponsored by DLFS and a major US funding program, Strategic Environmental R&D Program (SERDP). The campaign involved many scientists and contractors, including two scientists from CRREL, who are co-author of the present report.

Thiboutot, S., Ampleman, G., Lewis, J. Faucher, D Marois.A., Ballard, J.M., Martel, R., Downe, S. Jenkins, T. and Hewitt, A. 2003. Environmental Conditions of Surface Soil and Biomass Prevailing in the Training Area at CFB Gagetown, New Brunswick. DRDC TR 2003-152 Defence Research and Development Canada Valcartier.

Sommaire

Le contexte international de démilitarisation, de fermeture de bases militaires et les aspects plus rigoureux des lois environnementales ont conduit à l'établissement de nouveaux domaines de recherche. Plusieurs activités des forces armées tel que le tir réel de munitions, la démolition et la destruction de munitions jugées désuètes par détonation extérieure peuvent conduire à la dispersion de composés énergétiques dans l'environnement. C'est dans ce contexte que Recherche et Développement Canada-Valcartier (RDDC Valcartier) et le laboratoire américain Cold Regions Research and Engineering Laboratory (CRREL) ont initié des programmes de recherche dédiés à l'étude des impacts environnementaux des matériaux énergétiques qui sont trouvés dans les munitions des départements de la défense canadienne et américaine. Le programme de caractérisation des sols a placé nos départements dans une position où nous sommes prêts à répondre à des inquiétudes environnementales et a permis de développer une expertise unique. De plus, les programmes canadiens et américains sur l'étude de caractérisation des secteurs d'entraînement afin de comprendre les impacts environnementaux de l'entraînement militaire à tirs réels et ainsi répondre à quelque question que ce soit en relation avec ce sujet ou encore prendre des actions correctives si nécessaire. Le premier secteur d'entraînement qui a été caractérisé entre 1999 et 2001 est celui de la base de Shilo au Manitoba pour plusieurs raisons, incluant le fait que des troupes allemandes s'y soient entraînées pendant 23 années. Suite à l'expertise gagnée à Shilo, le Directeur des Forces Terrestres a mandaté RDDC-Valcartier afin de procéder à des études similaires sur d'autres secteurs d'entraînement majeurs des forces terrestres. Le secteur d'entraînement de la garnison de Gagetown du Nouveau Brunswick a été sélectionné en deuxième lieu basé sur son utilisation intensive par nos troupes et par des troupes alliées et basé sur sa nature complémentaire géologique et géographique par rapport au secteur de Shilo. La première phase a été effectuée en 2001 à Gagetown et a focalisé sur la qualité de l'eau de surface et de l'eau souterraine. Un premier rapport a été rédigé incluant la caractérisation hydrogéologique et géologique de la portion nord du secteur d'entraînement. Ce rapport détaille la phase 1 de ce travail qui a suivi incluant cette fois la caractérisation de sols de surface et de biomasse dans les sites de tirs majeurs du secteur. Ce travail a été financé en partie par le directeur des forces terrestres et par un programme de financement de la recherche américain appelé Strategic Environmental R&D Program (SERDP). La campagne a impliqué de nombreux scientifiques et contractuels, incluant deux scientifiques américains du CRREL, qui sont co-auteur du présent rapport.

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1. Introduction

Troop readiness involves intensive training in Canada. Moreover, many other countries use our training ranges under international agreements. Testing and training ranges are therefore key elements in maintaining the capability, readiness and interoperability of the Armed Forces. The current state of knowledge concerning the nature and extent of contamination of military testing and firing ranges is inadequate to ensure sound environmental management of these facilities as sustainable resources. Results of the on-going environmental research program will contribute to the development of recommendations for sustaining range activities while ensuring environmental stewardship and regulatory compliance. The potential for environmental impacts, including contamination of drinking water supplies, mandates that our departments demonstrate responsible management of these facilities in order to continue testing and training activities.

We need to provide national defence departments with techniques to assess the potential for groundwater contamination from residues of high explosives (TNT, PETN, RDX, and HMX) and other potential contaminants such as heavy metals or depleted uranium at testing and training ranges. We should develop site characterisation guidance and fill data gaps in fate and transport properties of high explosive residuals. Additional research will increase the knowledge base supporting the credibility of guidance and recommendations for range sustainability. The most extensive study achieved up to now was conducted at CFAD Dundurn where the impact of the open detonation of Canadian obsolete munitions was extensively studied [1]. The first actual training range visited was the CFB Shilo training area where detailed research was achieved to assess the environmental impacts of many types of live fire training [2-3]. Anti-tank firing ranges across Canada were also the topic of another study [4-6]. Moreover, many papers were written in recent years concerning the fate and analysis of explosives in various types of sites[7-19].

This topic also is of very high interest and profile in the United States. The new Army slogan is now "Protecting the Environment and our Country" and sustainable training is at the highest priority in the Pentagon and Congress. There is a growing concern about the potential of military training activities leading to groundwater contamination on the Department of Defence (DOD) ranges. An example of this situation exists at the Massachusetts Military Reservation (MMR). Military and law enforcement training has been conducted for over forty years in the Training Range and Impact Area, which encompass almost 14,000 acres at MMR. The Training Range and Impact Area lie directly over the Cape Cod Aquifer, which has been designated as the sole drinking water source for Cape Cod. This aquifer was contaminated by energetic compounds and other military related compounds such as perchlorates. Training at MMR was consequently suspended by the US EPA. This situation, combined with other evidence has led the Strategic Environmental Research and Development Program (SERDP), one of the most important corporate environmental research and development (R&D) program (DoD-DOE-EPA), to request proposals in the area of environmental impacts of training. This program covers many aspects in which R&D have to be dedicated to

better understand the complex fate of contaminants from military activities, including the characterisation of residuals from both high and low order detonations, the development of credible source term estimates for specific range activities, the understanding of the complex environmental fate or targeted parameters in training ranges, and the establishment of environmentally acceptable end-points. The second phase of this study was sponsored partly by the SERDP funding program from the USA.

This report presents the second characterisation phase (phase II) carried out at CFB Gagetown training area in October 2002. The first phase (phase I) was conducted in the fall of 2001 and was dedicated to the drilling of wells on the northern half of the base to collect groundwater samples and to perform the hydrogeological characterisation of the site [20]. Phase II of this work consisted in a joint effort both on surface and sub-surface where 26 wells were drilled and sampled in the southern half of the base and surface soils and biomass were collected. The information gained is of strategic value for CFB Gagetown and represents a detailed study on the characterisation of such a huge and intensively used training area. The Gagetown study will be complementary to the CFB Shilo based on its different geological context and based also on the nature of the training conducted there. This report presents the surface soil and biomass results while a second report will be published on the hydrogeological context of the training area. Fieldwork was conducted in the fall of 2002 and data treatment was done in the winter 03 and spring 03. This work was carried out under the Munitions and Firepower thrust 2n within the working breakdown element 12 ny 01 of DRDC-Val program and partially supported by SERDP.

2. Range History/Description

2.1 Geographical Location

CFB Gagetown is located 20 km southeast of Fredericton, New Brunswick, in the county of Queens and Sunbury (Figure 1). The Base covers an approximate area of 1100 square kilometres. The Training area can be divided in two physiographic regions, the New Brunswick Lowlands in the north and the Ste-Croix Highlands in the south. The north half of the territory is used by the military as the Static Range Impact Areas (SRIAs), and the south half of the base as a General Manoeuvre Area, Dismantled Manoeuvre Areas, Mountain impact Area that is used frequently. The Garrison is located in the northwest portion of the base.

2.2 History of Activities

The first army training activities at CFB Gagetown took place in 1954. The base is still used today as one of the major training facilities of the Canadian Forces in Canada. Several military schools such as Infantry, Field Artillery, Air Defence, Military Engineer and Armoured Schools are actively training in Range and training area (SRIAs). Such training activities represent potential contamination sources by energetic materials and metals for underlying soil and groundwater in most part of the SRIA. Moreover, CFB Gagetown training area is often used for foreign military training (US, UK and Australian troops). It is the main training area for other CF bases such as CFB Valcartier troops who often conduct training at CFB Gagetown due to its vast training ranges for high calibre live fire training.

2.3 Information Sources

Most of the information needed to support the writing of the present report was taken from CFB Gagetown military personnel mostly from Range control unit. The overview of the sensitive areas was also made possible with information and area map from a preliminary initial study [14]. Fieldwork and planning of related activities was authorised by M. Sheldon Downe, Land Forces Atlantic Area Environment Officer for CFB Gagetown. Pertinent information was also obtained from Explosive Ordnance Disposal unit (EOD) military personnel who always were present when sampling in a danger zone for safety reasons.

3. Experimental

3.1 Field Investigation

Fieldwork was conducted between October 1st and October 6th 2002 on the northern parts of the training ranges of CFB Gagetown and around base limits. The surface sampling was concentrated in the live fire impact areas located in the northern portion of the base (Fig.2). Sampling strategies were designed on site, depending of the landscape, visual observation of the area, the information gathered from the EOD unit personnel and also based on the expertise gained in previous training area field work (Fig.3). The surface soils and biomass sampling was supervised and conducted by Dr Sonia Thiboutot, Dr Guy Ampleman and Mr. André Marois from DRDC Valcartier and by Dr Thomas Jenkins and Mr Alan Hewitt from CRREL (Fig. 4). Mr. Jeff Lewis also participated in the surface soil sampling by collecting samples in rifle ranges after the departure of the surface sampling team.

3.2 Consultants and Contractors

Hydrogeological work was done under the supervision of Institut national de la Recherche Scientifique Eau Terre et Environnement (INRS-ETE) personnel, which included Richard Martel, Jean-Marc Ballard and Jeff Lewis. This team was responsible for the proofing of well locations with the help of electromagnetometers, drilling of wells and groundwater and surface water sampling. Wells installed in the phase I study were re-sampled and many new wells were drilled in various locations in the training area. The Dillon consulting firm, based in Fredericton was retained by Defence Construction Canada (DCC) to assist in the collection of samples and data for this environmental site assessment. The services provided by Dillon also included the following: initial project co-ordination, borehole drilling and well installation supervision, purge and development of well, groundwater sampling and all other related logistics. DCC also hired contractors for the UXO proofing (Dillon), the borehole drilling (Dayes Well Drilling and Boart Longyear) and the GPS surveys (Traynor Surveys Ltd. of Fredericton, NB). The analytical work on water samples for metals, perchlorates and general chemistry was performed by Research and Productivity Council (RPC) Laboratory located in Fredericton, NB.

3.3 Chemical Parameters and Analytical Methods

All groundwater (GW) and surface water samples were analysed for metals, major anions, and energetic materials (RDX, HMX, TNT, 2,4-DNT, Tetryl and their main degradation by-products). A sample of 500 ml of stabilized GW was passed through a Sep-Pak TM cartridge filter to absorb any explosive residues that may be present. Acetonitrile, 5 ml, was then passed through the Sep-Pak TM cartridges to extract the explosives residues. The extracts were treated according to EPA Method 8330 (US EPA 1994) [21]. Metals were analysed by Inductively Coupled Plasma Mass

Spectrometry (ICP/MS) by RPC Laboratory and all parameters available by this method were included in the study. Perchlorates were also analysed by RPC lab on a portion of the groundwater samples selected based on the known use of perchlorates in ranges up gradient of the groundwater. Energetic Materials were analysed by CRREL and DRDC Valcartier by HPLC and GC-ECD following EPA methods 8330 and 8095. [21].

3.4 Safety of the Sampling Teams

There were many sampling teams involved in the phase II campaign. They were split in six teams based on their roles and mandates in the campaign. A call sign (51 delta) was allocated by range control to the six teams who were as follows, respectively:

51 D1 – Surface sampling team

- Sonia Thiboutot (DRDC Valcartier)
- Guy Ampleman (DRDC Valcartier)
- André Marois (DRDC Valcartier)
- Jocelyn Trembaly (DRDC Valcartier)
- Tom Jenkins (CRREL)
- Alan Hewitt (CRREL)

51 D2 – Drilling team

- Jamie Wilson (Dillon Consulting)
- Don Daye (Daye's Well Drilling)
- David Daye (Daye's Well Drilling)
- Kevin Donald (Daye's Well Drilling)
- Larry Mason (Daye's Well Drilling)

51 D3 – Water sampling team 1

- Jamie Hunter (Dillon Consulting)

51 D4 – water sampling team 2

- Steve Hartman (Dillon Consulting)

51 D5 – UXO Clearance team

- Spencer Wilson (Dillon Consulting)
- Steve Borhese (Dillon Consulting)

51 D6 – INRS team

- Jean-Marc Ballard
- Jeff Lewis

The cell phone of main points of contacts were provided to all teams including the range control command post, the EOD manager (Sgt Paul), Mr. Jean-Frédérique Lalonde and Ms Ann Jones from DCC, the environmental officer of CFB Gagetown (Mr. Sheldon Downe) and range control scheduling responsible (Sgt Fronchak).

A schedule was established prior to the campaign in collaboration with Dr Thiboutot from DRDC Valcartier, Mr. Jean-Marc Ballard from INRS Georessources, Ms Ann Jones from DCC and range Control command post. The schedule was established based on a previous visit to the training area (spring 2001) an estimation of the time needed in each range to perform both surface and sub-surface sampling. The schedule is included in the attached CD, file Appendix A. Any modification to the accepted schedule had to be approved by Sgt Fronchak from range control. The schedule insured that a safety template was applied at all times with no live firing conducted nearby teams while they would be in the live firing area.

A detailed safety briefing was given to all teams on September 31st. Capt. Melancon, the new Range Control Officer of the training area welcomed the sampling teams to CFB Gagetown. He stated that the range control and EOD staff would be dedicated to the success of our sampling campaign and that they would give full support to our study. The safety briefing included detailed information on the type of munitions that the teams might encounter on ranges and how to minimise the danger associated by working in such an environment. Clear instructions were given on the liaison with range control either by cell phone or radio provided by range control. As for radio contacts, Motorola 100 were distributed to each sub-units who were instructed to use the Channel 1 for internal communication at a frequency of 47.66. It was specified to check on a daily basis for range availability, to insure that they would be informed of any changes that could be made to the Daily Range Safety Orders and to insure that EOD requirements were addressed for every sub-units. Each team had to always request permission to enter the danger red zones at the gate and to inform range control when exiting of the red zone. A team contact list and sign allocation sheet was written and distributed to all teams with clear instruction on whom to contact for each need at all times. More precisely, it was clearly indicated to all sub-units to remain in constant contact with main point of contact and sub-units had to identify their call sign when addressing main point of contact.

Eight EOD specialists were dedicated to the sampling teams and were always to be present with team when entering a red danger zone. They actually drove and walked all day with teams to insure their safety when in a danger zone. They also provided useful and detailed information on each of the range sampled by identifying for the teams the highest impact area in each range.

3.5 Sample Handling and Treatment

Explosives are not volatile compounds and therefore, no specific precautions such as the use of sealed containers have to be taken during sampling of media containing explosives. Composite soil samples were collected comprised of 20 to 30 randomly obtained increments. These bulk samples were stored in polyethylene bags. The biomass samples were stored in large commercially available polyethylene bags. The bags were labelled and were immediately stored coolers on ice, in the dark to avoid the photodegradation of light-sensitive compounds. At the end of each day, the samples were transferred to a freezer. The use of polyethylene bags decreased the space needed for storing samples and reduced shipping costs. The samples were shipped frozen to DRDC Valcartier, who dried them under the dark for 24 hours, under a hood, then homogenised them by adding 50 ml of acetone and mixing the resulting slurry thoroughly. The dried and homogenised samples were sieved on a 25 mesh sieve and split into three sub-samples. One set of samples was sent to CRREL for explosives analysis, another set was sent to RPC for metal analysis and the remaining set was kept at DRDC Valcartier for explosive analysis. Biomass samples were collected in polyethylene bags, kept frozen in the dark and sent directly to RPC laboratory for metal analysis. Digestions of the finely cut plant materials were done on all biomass samples for metal analysis. For explosive analysis, one biomass sample collected in a pond down gradient of a high impact area was lyophilised, extracted and analyzed at DRDC Valcartier.

3.6 Sample Labelling System

All of the collected samples were named according to the following five-part labelling system:

First part: sample type

- | | |
|----|---|
| S: | Soils |
| B: | Biomass (Prairie Grass and other species) |

Second part: Location by range

- | | |
|-----|---|
| AA: | Anti-Armour Range |
| AR: | Argus Impact Area |
| BG: | Background samples collected outside of training area |

CGR: Castle Grenade Range
 GF : Greenfield Range
 H : Hersey Impact Area
 L : Lawfield Impact Area
 NCRGR : New Castle Rifle Grenade Range
 NCHGR : New Castle Hand Grenade Range
 WAT : Wellington Anti-Tank Range

Third part: Identification of the sample source

Target number (1, 2 and 3) or

Background location by GPS or;

LS for linear sampling at XX% of the range, where XX%= % of the overall range length or;

FP (firing position), xm, x being the distance from the firing position or;

Left, Mid or Right when sampling only on these portion of ranges or;

Core, when depth sampling was conducted with position specified or;

Xm: In grenade range when only linear sampling was done perpendicular to the firing point, x being the distance from the firing point or;

Crater: when sampling around or in craters with GPS position of the crater sampled or;

HS: when Hot spots were located on the range, followed by a GPS position.

Fourth part: Identification of the sample

A or B for the linear sample, A being in the eastern portion and B in the western portion from the middle of the range, starting point on the access road.

GPS position

Fifth part: Date of Collection

4. Range Description and Sampling Strategy

The surface sampling team collected 137 soil and 58 biomass samples in the following ranges : Anti-Armour range (AA), Old Castle grenade range (CGR), New Castle Rifle and Hand grenade ranges (NCRGR, NCHGR), Wellington Anti-tank range (WAT), Argus Impact Area (AR), and Lawfield, Hersey and Greenfield Impact area(L,H,GF). These ranges were selected based on their intensive use by the troops and based on their representativeness of specific types of ranges. Later on, the small arms ranges were sampled by Mr. Jeff Lewis from DRDC Valcartier. Soils and biomass collected in these later ranges were analysed for metals only. The sample ID, their GPS positions and some pertinent information on each sample can be found in Tables 1 and 2 (see CD inserted at the end of the report).

Many sampling patterns were used in the present study, based on our combined previous experiences and based on the visual inspection, the presence or absence of targets and the general settings of the ranges visited. In general, linear transects patterns (Fig.5) were used in the artillery ranges and large impact area. Circular sampling was used around targets (Fig.6) and linear sampling pattern were used for firing position at various distances from the firing position (Fig.7). Mostly surface soils (from 0 to 5 cm deep) were collected; however, some core samples were collected in specific area of interest. The cores were collected with a manual corer designed by the CRREL team. It allowed easy sampling between 0 to 10 cm deep, with the possibility of discriminating at least 3 layers of sub-samples (Fig.8).

4.1 Background Samples (BG)

The data obtained for soil and biomass were compared with accepted thresholds criteria for each of the specific analytes measured. When such criteria are either not available or not published, it is highly interesting to compare the results with mean results obtained on the largest amount of representative background samples. For this reason, 16 soils and 12 biomass samples were collected in a close distance outside the live fire training area (in the dry zone, where no live firing is allowed). The limited number of representative background samples will not allow a statistically detailed comparison with actual live firing ranges sample data. However, distinct trends would indicate the potential for metals to accumulate. Access roads were available in all directions around the training area and it was relatively easy to drive around it and collect samples at regular intervals around the area. GPS positions of all samples are reported in Tables 1 and 2 (CD attached). The labelling was: S-BG-GPS position and B-BG- GPS position.

4.2 Anti Armour Range (AA)

A total of 32 soil and 8 biomass samples were collected in the Anti Armour range. This range was used for 105 and 155 tank rounds toward three tank targets and also for the firing of smoke grenades. AA range is located in the northern part of the training area, approximately at one km south of the Shirley road. It is approximately 7 km² and is split by a trail that runs north to south in the middle of the range. It is mainly flat and prairie grass covered for the two first km from north to south, and presents small hills in its southern portion (Fig.9). On top of the hills in the southern portion are three target tanks located, respectively, at the following GPS positions: Target 1 (T1): 04673 76868, Target 2 (T2): 04519 76882 and Target 3 (T3): 04618 76204 (Figs. 10-11). Firing position number 4 is located directly in the middle, at the northern entrance of the range at GPS position: 04805 78895. An Expray field test kit [21] was used to verify the content of a cracked 105 mm UXO found in the AA. The result was negative and the UXO was identified as an inert (Fig. 12)

The following samples were collected:

A) Composite samples of surface soil and vegetation (20 increments each) were collected along linear transects (Fig. 5) perpendicular to a centre line at 20%, 40%, 70% and 100% of range, going from firing point to targets. Composite A included samples taken east of center; composite B included samples taken west of center. The labelling was S-AA-LS-x%-A or B for soils and B-AA-LS-x%-A or B for biomass.

B) Composite soil samples (30 increments) were collected at 1 m and 5 m around target tanks numbers 1, 2 and 3 (Fig.6). The labelling was S-AA-Tx-Comp 1 or 5m.

C) Discrete soil cores were collected in front of the one (T1) and two (T2) targets, which appeared to have been the most used. One sample was collected 1.5 m in front of T1 and another 1 m in front of T2. Cores were split between 0-2 cm and 2-5 cm. The labelling was: S-AA-Tx-core-y cm front.

D) Two samples were collected around T3. Composite surface soil samples were collected at both 1 and 4 m distances from the target tank (fig. 6). The labelling was: S-AA-T3- 0-1, and 5m comp.

E) Composite soil samples (30 increments) were collected in front (avant/northern) and in the rear (arrière/southern) of the three targets. The labelling was S-AA-Tx-avant/arrière. The 30 sub-samples were collected in a rectangular pattern of the same width as the target between 0 and 5 m from the target (Fig. 13).

F) A composite sample (20 increments) was collected in the dry drainage channel in front of target 2. The labelling was: S-AA-T2-runoff (Fig.14).

G) Composite samples (20 increments) were collected in perpendicular lines of 25 m width of the firing position number 4 at 0, 10, 20, 30, 40, 50 and 100 m from the firing position (Fig. 7). The labelling was: S-AA-FP xm.

4.3 Wellington Anti Tank Range

A total of 18 soils and one biomass sample was collected in the Wellington anti-tank range. The range is located north of the Argus and Greenfield Impact area and is approximately 5 km². It is located in the northern part of the training area at the intersection of the Shirley and the Schanes roads. There are six target tanks on the range at various distances from the firing position (T1 to T6). Figure 15 illustrates the relative positions of the firing position and the target tanks. Target one to five are respectively the nearest and the farthest from the firing position, while target six was located on the other side of a small internal road within the range. Target number six area was not sampled based on its lesser use by the troops. The WAT was covered with shrapnel and propellant residues (Fig. 16-19).

The GPS positions of the five sampled targets (T) and firing position (F) were as follows, respectively:

T1: 00998 77317

T2: 01003 77311

T3: 01042 77271

T4: 01062 77245

T5: 01084 77206

FP: 00849 77364

The Expray field test kit was used on remains of material that appeared to be solid rocket fuel, found near targets one and two. The test gave a positive response to the second reactive can, which is indicative of a dual or triple based propellant.

The following samples were collected:

1. Composite surface soil samples (20 increments) were collected around five target tanks, at 1-4m distance around targets (fig. 20). The labelling was: S-WAT-T1 to T5.
2. Near surface soil profile samples (at 0-2 cm, 2 to 5 and 5 to 10 cm depths) were collected in front of the target tank number 2. The labelling was S-WAT-depth (x-y).
3. At the firing point composite surface soil samples were collected in front of and behind the firing position in a rectangular pattern of the same length as the firing line and of a width of approximately 2m (Fig.21). The labelling was S-WAT-FP-Front or back.
4. Composite (10 increments) core samples were taken along transects at 10, 20 and 50 m from the firing position and soil between 0-2 cm and 2-5 cm were composited together (Fig. 22). The labelling was S-WAT-FP-CORE- xm (x-y).

5. One composite sample (30 increments) was collected in an OD pit adjacent to the firing range, used frequently for the OD of unexploded anti-tank rounds. This sample was labelled S-WAT- OD pit.
6. One composite biomass sample (30 increments) was collected in a circular pattern at 1- and 5-m from targets number one and two.

4.4 Old Castle Grenade Range

A total number of 7 soil and 4 biomass samples were collected in Old Castle grenade range. The range was decommissioned two months prior the sampling campaign. In the past, the range was used both for the firing of 40 mm rifle grenades and hand grenades. The surface of the range was graded after decommissioning and, therefore, the soil profiles were disturbed. It was still decided to sample the range, based on previous studies conducted both in Canada and USA on similar ranges [2,3,]. For any further need, the GPS position of the middle of the old range was recorded to be: 02761 79732.

The following samples were collected:

- A) Three composite surface soil and biomass samples were collected within the impact area at the left, in the middle and at the right hand side of the range when facing it. The labelling was S-or B-CGR-left, mid or right.
- B) Six core samples were taken, compositing the sections between 0-2cm, 2-5 cm and 5-20 cm depths on the right side of the range where debris were found. The labelling was S-CGR-core x-y cm.

4.5 40 mm New Castle Rifle Grenade Range (NCRGR)

Two soil and one biomass sample were collected in NCRGR range. This range has not been made operational as of this date. No hand grenades have even been fired on the range; only 40-mm rifle grenades. In the past, this portion of land was part of the ricochet area of the Argus Impact range (artillery). The NCRGR range is located at the entrance of the training area, north of Argus Impact area. The soil behind the two wooden targets was sampled. The GPS positions of the two targets are 0178 7669 (T1) and 0221 76678 (T2).

The following samples were collected:

- A. Two composite surface soil samples (20 increments) were collected behind targets. The labeling was S-NCRGR-T1 or T2 back.
- B. One composite biomass sample (20 increments) was collected behind target one. The labeling was B-NCRGR-T1

4.6 New Castle Hand Grenade Range (NCHGR)

Six soil and 4 biomass samples were collected in the NCHGR range. This range has been in operation for only 9 months. No rifle grenades have even been fired on the range, only hand grenades. Six soils were sampled following a pattern illustrated in Figure 23 by sampling linearly, parallel to the front wall of a recently built bunker at 10, 20, 30, 40 and 50 m distance. Four biomass samples were collected including a field duplicate on the right and left side of the range when facing it, and in the rear of the range.

The following samples were collected:

- A. Composite surface soil (30 increments) in lines parallel to the bunker. The labeling was S-NCHGR-xM.
- B. Composite vegetation samples (20 increments) were collected within the impact area. The labeling was B-NCHGR-Rear, Front or Left.

4.7 Hersey Impact Range (H)

Fifteen soil and 14 biomass samples were collected in H impact area. Hersey impact area is an artillery range that is mostly used in conjunction with Lawfield impact area for high explosives (HE) rounds and illuminating rounds. It is approximately 19 km² and is located northeastern of the training area. There is a dirt road in its middle that runs from northeast to south-west (Hersey road). It is relatively flat and highly prairie grass covered, with the visual presence of many craters from past detonation events. The sampling team chose the linear transept approach (Fig. 5), applicable for this huge range and choose the Hersey road as the middle point of the transepts. GPS positions were calculated to locate the 40, 60, 80 and 100 % transepts. Moreover, the sampling team decided to sample in transepts while sampling preferentially in and around craters in the transepts. This was decided due to the high number of visible craters in all transepts. This would be considered as a new sampling approach combining both the composite transept pattern and many discrete crater sampling in the same transept. Due to the presence of a thick layer of prairie grass, the manual auger tool was used for all samples. After samples were collected in craters, the first layer of grass was removed to uncover the first cm of soils that were successfully collected. Various field duplicates were also collected.

The following samples were collected:

- A. Composite surface soil and vegetation (20 increments) samples were collected along linear transepts in and around craters on either side of centre line (Hersey road) at approximately 500m distances down range from the centre line. Note: Several craters had an area that was covered with a whitish substance. The A sub-samples were located east of Hersey road while the B samples were located west of Hersey road. The labelling was S-H-x% A or B and B-H-x% A or B.

- B. A very fresh crater area located at GPS position 08721 73805 was composite sampled (20 increments) with a circular pattern within a radius of 0-5 m from the centre of the crater. The labelling was: S-HS-GPS position.

4.8 Lawfield Impact Range (L)

Nineteen soil and 9 biomass samples were collected in L impact area. It is approximately 12 km² and is located southeast of the Hersey impact area. A dirt road runs through it from west to east (Argus East Road). The sampling strategy that was selected in Lawfield was the preferential sampling of craters, without the linear transept approach except for the 25 % transept. This was done to compare the results acquired in Lawfield and Hersey to refine our global approach. Results could lead to future directions in sampling artillery ranges (linear transepts versus discrete locations at craters).

The following samples were collected:

- A. Several composite surface soil and vegetation samples were collected around impact crater clusters (2-4) in the middle of the range. Note: Several UXOs and large pieces of casing were present on the surface and samples were collected around these potential contaminated sources (Fig. 24-25). The labelling was: S-or B-LS-HS- GPS position.
- B. Cores were also taken in the middle of two fresh impact craters, separating 0-2, 2-5, and 2-10 cm increments. The labelling was S or B-L-25 % A or B, A being north of centre line and B south of centre line.
- C. Composite surface soil and vegetation (20 increments) samples were collected along linear transepts on either side of centreline at 25% of range. Note: Numerous impact craters were present at this distance; however, none appeared to be fresh.

4.9 Argus Impact Area (AR)

In Argus wood, a total of 18 soil and 1 biomass sample were collected. The AR impact area is an HE live-firing range heavily used by artillery. Troops fire many types of rounds including the following: 66 and 84 mm rockets, simulated anti-tank mines, 60- and 81-mm mortar, 105- and 155-mm artillery projectiles, 500-pound bombs, white phosphorus munitions, 40-mm rifle grenades, C4 blocks (70 pound blocks for demolition trials), smoke rounds, M203 grenades, Trigran for creating craters (a cratering explosive based on granulated Tritonal (80% TNT, 20% aluminium) , 2.75-inch rockets, and ADATS and TOW missiles. Two weeks prior to our sampling campaign, a major exercise named "Staunch Gladiator" was conducted on AR. This exercise involved the firing of all types of munitions stated earlier in this paragraph. This exercise is an annual event in which live firing was conducted for a civilian and military audience to demonstrate the firing capabilities of our troops.

The range is approximately 11 km² with many dirt roads that runs through it in all directions to provide access to the various target areas. At the entrance of the range is a company defence position, which is an elevated area on which the main firing points are to be found. The two EOD staff personnel dedicated to the surface sampling team explained with great details the Staunch Gladiator exercise and guided the team exactly to all target and crater locations for sampling. In the northern part of the range, all targets and craters formed by the use of C4 or Trigran were sampled (Fig. 26). At the south end of the range, in a heavily cratered area located on the top of a small hill various locations in and around the craters were sampled. One crater (crater # 4) was of particular interest because it contained reddish water and a large piece of white-grey residue, which suggested a low order detonation of a 500 pound bomb (Fig 27). The grey-white solid gave a positive test for TNT with the Expray field test kit. The crater surface water was also sampled to verify if the reddish colour was due to the presence of photo-degraded TNT.

A biomass sample was collected in a pond down gradient of the cratered area (Fig. 28). This pond was formed by many rivulets coming from the cratered area. The biomass sample was analysed for energetic materials.

The following samples were collected:

- A. Composite surface soil sample (20 increments) was collected inside and around the rim of a large impact crater created by the use of C4 and Trigran. The labelling was S-AR-Crater in and out.
- B. A composite surface soil sample (20 increments) was taken in front and at the left of two cement block targets labelled T1 and T3. The labelling was S-AR-Tx-front or left.
- C. A composite surface soil sample (20 increments) was taken in front a target tank. Pieces of propellant were visible on the surface. The labelling was S-AR-T2- front.
- D. Circular composite surface soil samples were taken around three 500-pound bomb craters at radii of 1, 2 and 5 m from the centre of the crater (Fig. 29). One sample was also collected within 0-1 m of the centre of the crater when possible (if no standing water was in the crater. This was labelled "around."). One of the craters (crater 4) had standing water that was coloured red-orange. A 2-4pound piece of light grey material in the crater gave a positive response to the 1st Expray reagent, suggesting the presence of TNT. In addition, several large fragments of the 500-pound shell were present in and around the crater with the coloured water. This crater was believed to be from the partial detonation of a 500 pound bomb The labelling was S-AR-crater 1 to 4, 1 or 2 or 5m or around).
- E. Samples were collected around two 2.75-inch rocket crater (crater 5 and 6). The labelling was S-AR-crater 5 or 6 and GPS position.
- F. Biomass was sampled for explosives analyses in a pond down-gradient of the cratered area. The labelling was B-AR-GPS position.

4.10 Greenfield Impact Area

Four soil and 4 biomass samples were collected in Greenfield Impact Area. The Greenfield impact area is located south of the Anti-Armour range, between Hersey and Argus Impact areas. Greenfield is considered by military personnel as a “ricochet” zone, or bouncing zone for Argus, Hersey and AA ranges. Greenfield is approximately 12 km² and is highly grass, bush and tree covered. No trails cross the range; therefore, use of a vehicle within the range, even an all wheel drive vehicle, is problematic. Sampling was limited to a total of four soil samples and four biomass samples in the two accessible transects, based on the limited use of the range for direct firing, on the absence of targets and on the high vegetation present on the range. Only the 40% and 60% transects were sampled, the 40% being near the north-south road coming from the anti-armour range at a GPS position of 04650 75199. The GPS position of the 60% transept was 05498 74504. Composite A samples were collected south of the mid section, while B samples were collected north.

The following samples were collected:

- A) Composite surface soil and vegetation samples (20 increments) were collected along linear transects on either side of centre line at 40% and 60% of range, going from firing point to targets. The labelling was: S or B-GR-LS-x% A or B.

4.11 Small Arms Ranges and Burning Area

4.11.1 Small Arms Ranges

To verify their potential contamination by heavy metals, three representative small arms ranges were sampled according to a sampling pattern previously used in the Shilo training area [2,3]. The ranges were located in the same area and were named Batouche, Reichwald and Vimy. Batouche and Vimy ranges presented 12, while Reichwald presented 20 targets. Composite surface soil samples were collected by combining sub-samples collected in front of three targets.. Some subsurface soils were also collected from 10 to 40 cm deep with the help of a manual auger to verify the vertical profile of contamination. The following samples were collected:

- A) Five samples were collected in Batouche in front of targets 1 to 4, 5 to 8, 9 to 12; one duplicate and one deeper sample was collected in front of target 12 (Fig. 30). The labelling was S-Batouche x-y or S-Batouche 12-Depth.
- B) Six samples were collected in Reichwald in front of targets 1 to 4, 5 to 8, 9 to 12, 13 to 16 and 17 to 20, and one depth sample was collected in front of target 1 (Fig.31). The labelling was s-Reichwald-x-y or S-Reichwald-1-Depth.
- C) Four samples were collected in Vimy in front of targets 1 to 4, 5 to 8, 9 to 12. One depth sample was collected in front of target 1 (fig. 30). The labelling was S-Vimy x-y and S-Vimy-1depth.

4.11.2 Burning Area

A recent decision was made at Gagetown training area to bring excess artillery propellant to two centralized locations for burning as opposed to burning in the field wherever the artillery guns happened to be firing. This decision was made to better control the burn procedure. Therefore, burn pads of concrete approximately 20 cm thick were installed at each burn location in order to prevent the burned residues from contaminating the soil. The burn pads are rough slabs approximately 2 m x 2 m located in the middle of a large flat area cleared of vegetation. The two burning pads and the surrounding areas were sampled to verify the localized impact of this activity. The two locations were identified as Airstrip-2 and Lawfield.

At both locations, despite the presence of the concrete pad, large amounts of propellant had obviously been burned on the adjacent ground. These burn marks were clearly evident visually as scorched and blackened strips approximately 30 cm wide by 3 to 5 m long directly on the soil. The preference for burning excess propellant is to lay it out in long narrow piles of these dimensions, which the concrete pad cannot accommodate. Use of the pad greatly increases the amount of time required to dispose of the propellant as relatively small amounts can be burned at any one time on the pads. This accounts for the propellant being burned on the ground very close to the burn pad. The burn marks were sampled by making a composite of a dozen discrete surface soil samples taken along the length of the burn mark. Almost every burn mark had small amounts of unburned propellant along its outer extremity. Some of this propellant was included in the composite sample.

The burn pads themselves were blackened and had clearly been used for their intended purpose. The concrete, being very rough and porous, could not be methodically sampled. Instead, the soil immediately beside the pads was sampled, in the water run-off channels caused by rain. The samples were composites of at least a dozen increments samples each.

5. Results and Discussion – Energetic Materials

Results of sample analyses by the RDDC, CRREL and RPC laboratories were in excellent agreement. Plots of the concentrations obtained for TNT by both CG-ECD and HPLC and for, HMX at RDDC versus those at CRREL are presented in Figures 32 to 35 (see attached CD).

Analysis for NG was conducted at CRREL only. Instead of complicating the discussion with results from both laboratories, the results from the analysis at CRREL will be presented in the text. Values from both laboratories are given in Tables 3 aa through kk (see attached CD).

5.1 Background Samples

The results from analysis of the 16 background soil samples are presented in Table 3 aa. TNT was detected in all 16 samples with concentrations ranging from 10.6 to 2,410 µg/kg. This result was totally unexpected and might indicate that either the areas chosen to collect these samples had been impacted by live fire activity, which is highly unlikely considering the remote locations chosen for background sampling, or that TNT was cross contaminated when samples were processed. Another possible explanation could be that there is a chromatographic interference that we were unable to separate from TNT. The possibility of interference is remote, however, because HPLC analysis also indicated the presence of TNT in some of these sample extracts. The two transformation products of TNT, 2ADNT and 4ADNT, were only detected in one of these background samples. In past studies, these transformation products are almost always present in samples where TNT is detected. If cross contamination occurred during sample processing, no microbiological processes would be expected to take place because the soils were air dried at this point. Additional sampling at Gagetown will be conducted in the fall of 2003 and the problem associated with TNT in these samples will be investigated to resolve this issue.

Other target analytes were largely below detection limits for these background soils, although NG was detected in one sample, 2,4-DNT in one sample, RDX in three samples (concentrations at or below 5 µg/kg), 2ADNT and 4ADNT in one sample, and HMX in one sample. If cross-contamination of TNT occurred for these samples, it apparently did not affect the other target analytes.

Because of the concern for TNT in the samples collected at Gagetown and a potential overestimation due to a co-elution interference, the reporting limit for TNT was raised to 100 µg/kg and values obtained below this value will be reported as <d for all data sets except the background samples.

5.2 Anti Armour Range

The results from the analysis of soil samples from the Gagetown Anti Armour Range are presented in Table 3 bb. At the Anti Armour Range, samples were collected at the firing point, at various distances downrange between the firing point and the targets, and at several tank targets within the impact area. The munitions fired at this range are predominantly 105-mm and 155-mm rounds.

At the firing point, concentrations of NG and 2,4-DNT were detected in all surface soil samples collected from the firing line out to 100 m from the firing line (Fig. 6). For NG, the concentrations varied from 7,540 $\mu\text{g/kg}$ at a distance of 10 m from the firing line to 210 $\mu\text{g/kg}$, 40 m from the firing line. At 100 m, the concentration of NG was 624 $\mu\text{g/kg}$. For 2,4-DNT, concentrations declined from 4,520 at a distance of 20 m from the firing line to 14.2 $\mu\text{g/kg}$ 100 m from the firing line. The presence of 2, 4-DNT in these samples is consistent with firing point sampling for areas where 105-mm howitzers are fired using single-based propellant in which 2,4-DNT is present [22]. The presence of NG is due to the firing of the 155-mm rounds that use triple-based propellant containing NG. The locations and concentrations of NG and 2, 4-DNT at the Gagetown Anti Armour Range firing area are similar to that found at the Yakima Training Center Multipurpose range complex, where 120-mm tank guns are fired [23-27].

Results from the linear transect composites collected at various distances between the firing point and impact area also showed detectable concentrations of NG and 2,4-DNT. Except for NG, concentrations were generally below 100 $\mu\text{g/kg}$. The concentrations of NG in these samples ranged from 24.7 $\mu\text{g/kg}$ at 70% of the distance down range to 1,850 $\mu\text{g/kg}$, 20% down range.

At the impact area, samples were collected around three tank targets. At target 1, RDX was detected (58.6 $\mu\text{g/kg}$) in the surface composite sample collected at distances of 1 m around the target, and TNT (37 $\mu\text{g/kg}$) was detected in the composite collected 5 m around the target. A much higher concentration of TNT (4,620 $\mu\text{g/kg}$) was detected in a discrete core sample (0–2-cm depth) collected 1 m from the target. At the 2–5-cm depth, the concentration of TNT was reduced to below the 100- $\mu\text{g/kg}$ reporting limit.

At target 2, concentrations of RDX, HMX, and NG were detected in the 1-m surface composite at concentrations of 280, 166, and 28 $\mu\text{g/kg}$, respectively. At 5 m, the concentration of RDX was 31 $\mu\text{g/kg}$, NG was 20 $\mu\text{g/kg}$ and the other analytes were below a reporting limit of 10 $\mu\text{g/kg}$. RDX was also detected in a surface composite collected in front of the tank target.

For the third target, the concentrations of RDX in the surface composite samples collected around the target were much higher than at the other two targets. Concentrations of RDX around the targets at distances of 1-m and 5-m were 1,380 and 308 $\mu\text{g/kg}$, respectively. The concentration of RDX in the surface composite collected 1 m in front and back of the target were 4,220 and 112 $\mu\text{g/kg}$. Likewise, the HMX concentration in the two composites collected around the target were 320 and 44 μ

g/kg, respectively. The transformation products of TNT, 2ADNT and 4ADNT, were not detected in any of these samples.

The concentrations of RDX and HMX near target 3 were much higher than we have observed previously near artillery targets at Camp Guernsey, WY and Ft. Bliss, NM [23] or around artillery craters at Ft. Lewis, WA [22] where 105-mm and 155-mm howitzers were fired. Because the concentrations of RDX and HMX were greater than TNT for these Gagetown samples, these residues are probably from 105-mm rounds that contain composition B, or from blow-in-place detonations of duds using C4, rather than TNT-filled 155-mm rounds. The reason for the much greater concentrations detected for target 3 compared to targets 1 and 2 is uncertain, but may be a reflection of the occurrence of a low-order (partial) detonation near target 3 at some time in the past.

5.3 Wellington Antitank Rocket Range

Analytical results for soil samples collected at the Wellington Antitank Rocket Range and analyzed at DRDC-Valcartier (RDDC) and CRREL are presented in Table 3 cc. Nitroglycerin (NG) was a target analyte for the analyses conducted at CRREL only.

At the firing point, concentrations of NG exceeded all other energetic compound by several orders of magnitude. Values in the surface soil (0-2 cm) ranged from 424,000 µg/kg (ppb), 10-m in front of the firing line, to 14,100 µg/kg at 50-m from the firing line (Fig. 21). Because the antitank rockets used at this range (66-mm M72 LAW rocket) create a back blast, the concentration in the soil sample collected behind the firing line was enormous (11,300,000 µg/kg or 1.13%). If you assume that the NG in this sample is imbibed within a nitrocellulose (NC) matrix, the concentration of NC in the surface soil must be 3-5%. No analyses for NC were conducted with these samples since this polymeric material is particularly difficult to extract and quantify in a soil matrix.

The NG concentrations in the surface soil at Gagetown are much higher than found for surface soils at antitank firing ranges at the Yakima Training Center, Washington and Ft. Bliss, New Mexico [23]. The results are similar, however, to samples collected at an antitank rocket range at Schofield Barracks, Hawaii (Hewitt et al. in press). At Yakima, the highest NG concentration 5-10 m in front of the firing line was 3,600 µg/kg and at Ft. Bliss the highest concentrations in front and behind the firing line was 1,600 and 1,100 µg/kg, respectively. At Schofield, NG concentrations behind the firing point were as high as 1,390,000 µg/kg [25]. Visually, the Wellington range appeared to be used to a much greater extent than those at Yakima and Ft. Bliss, and it is this more intense usage that undoubtedly accounts for the higher concentrations observed here. At Schofield, mostly sub-caliber practice rounds are fired, thus the level of activity cannot be judged based on debris at the impact area. Thus it is difficult to visually assess the level of activity at the Schofield range.

NG concentrations at the depth interval of 2-5-cm below ground surface were also determined at 10, 20, and 50 m in front of the firing line at the Wellington Range (Fig. 21). The concentrations ranged from 34,000 $\mu\text{g/kg}$ at the 10-m location to 2,300 $\mu\text{g/kg}$ at the 50-m location. The concentrations for these three shallow subsurface samples were about one order of magnitude lower than the surface samples collected at a 0-2-cm depth. No subsurface samples were collected at the firing point at Ft. Bliss or at Yakima Training Center.

The relatively high NG concentrations in the shallow subsurface at Wellington are surprising because the half-life of NG in soil has been estimated in previous experiments to be less than one day [26]. This half life estimate refers to NG in equilibrium between soil moisture and sorption sites on the soil, but the NG present in the soil at Gagetown is probably still imbibed within a nitrocellulose matrix and thus not subject to the degradative processes within the soil. Future studies at antitank ranges should collect subsurface samples at deeper depths to see if the NG is penetrating into the soil profile. However, to our knowledge, NG has not been reported in groundwater samples collected at training ranges in Canada or the United States.

Firing point samples at Wellington also contained TNT, and occasionally HMX, but concentrations were much lower than for NG. The presence of TNT in firing point soil samples was unexpected; we did not find TNT in any of the soil samples from firing points at Yakima, Ft. Bliss, or Schofield Barracks. In addition, the two transformation products of TNT were not detected in these samples. Thus these results, while higher than our elevated reporting limit for TNT, appear suspicious and more sampling will be conducted to attempt to verify these data.

The concentrations of HMX far exceeded those of any other energetic compound for samples from the impact area at the Wellington antitank range. Concentrations of HMX in surface soils (0-2 cm) collected around five tank targets ranged from 74,200 to 1,290,000 $\mu\text{g/kg}$ (Fig.14). HMX accounts for 70% of the high explosive in octol, the explosive composition used in 66-mm M72 LAW rockets, which is the major munition fired at this range. The concentrations of TNT in these samples are generally about two orders of magnitude lower than HMX with values ranging from 330 to 22,800 $\mu\text{g/kg}$. TNT is present in octol at 30%, but it has very different fate and transport properties that account for the much lower concentrations found relative to HMX. The two major transformation products of TNT, 2-ADNT and 4-ADNT were also found in surface soils in these samples. Concentrations ranged from 104 to 1,980 $\mu\text{g/kg}$ and were always much lower than for TNT. Concentrations of RDX in soil samples from the impact range were even lower than for TNT. The maximum concentration of RDX in surface soil samples was 2,280 $\mu\text{g/kg}$.

Concentrations obtained for surface soils near targets at antitank impact areas at the Arnhem range at Valcartier [17,18] and Ft. Ord [27] are in excellent agreement with the results at Gagetown. Concentrations of HMX are in the hundreds to low thousands of mg/kg (ppm) and the ratio of HMX to TNT is generally about 1:100. For samples collected at Yakima, the HMX concentrations were generally about an order of

magnitude lower, but the ratio of HMX to TNT was similar to that found for antitank ranges at Gagetown, Valcartier, and Ft. Ord.

The concentration of HMX in shallow subsurface soils was only obtained for one core sample at Gagetown. The concentrations were 846,000 $\mu\text{g}/\text{kg}$ for 0-2-cm depth, 1,130,000 $\mu\text{g}/\text{kg}$ for the 2-5-cm depth, and 932,000 $\mu\text{g}/\text{kg}$ for the 5-10-cm depth. The concentrations of TNT in these samples were 2,420 $\mu\text{g}/\text{kg}$ for the 0-2-cm sample, 13,800 $\mu\text{g}/\text{kg}$ for the 2-5-cm sample, and 9,300 $\mu\text{g}/\text{kg}$ for the 5-10-cm sample. Thus it appears that HMX and TNT are deeper in the soil profile at the Gagetown site than found elsewhere [29], but more core samples should be obtained, and at deeper depths, to confirm this finding.

NG was also found in surface soils around these tank targets at concentrations ranging from 9,700 to 42,800 $\mu\text{g}/\text{kg}$. NG is present in the propellant for M72 LAW rockets and these rockets are propelled all the way to the target unlike artillery rounds. Thus, all of the NG in these rockets is not expended when impact occurs. The presence of NG near the targets is, therefore, not unexpected. NG was also found in shallow subsurface samples at concentration of 20,400, 15,000, and 43,600 $\mu\text{g}/\text{kg}$ for the 0-2-cm, 2-5-cm, and 5-10-cm samples, respectively. As found at the firing point, the penetration of NG into the soil profile was unexpected. More samples should be collected to verify this result.

5.4 Old Castle Grenade Range

The results for the soil samples collected at the Old Castle Grenade Range are presented in Table 3 dd. As you will recall, this range had been used for both hand grenades and rifle grenades, but had been closed and the surface soil had been graded two months prior to sampling. RDX was detected in all four surface composite samples at this range, and in the core samples as well. TNT was detected in several surface samples and in two subsurface samples as well. The concentration in the sample collected at the 2-5-cm depth was higher than at the surface probably because the soil had been graded prior to our sampling, redistributing the residues. 2ADNT and 4ADNT were detected in the subsurface samples, as well, supporting the presence of TNT in these samples.

RDX was also detected in all of the samples collected from this range. Concentrations varied from 15 to 364 $\mu\text{g}/\text{kg}$. In the samples from the soil core, the highest concentration of RDX was found at the deepest depth (5-10 cm) and the lowest at the surface, again demonstrating that the soil had been reworked or that RDX leached through the soil profile. The only other residues detected in these samples were HMX, 2ADNT and 4ADNT with concentrations generally less than 50 $\mu\text{g}/\text{kg}$.

The residues detected at this range are indicative of the type of explosives used in hand grenades and 40-mm rifle grenades, namely Composition B. This formulation is composed of RDX/TNT at a ratio of 60/40. HMX is an impurity in RDX and tends to remain at the surface, relative to RDX, due to its lower solubility in water. The concentrations found at this range were generally lower than we have found for

grenade ranges at Ft. Lewis or Ft. Richardson, probably due to range closure and the soil grading that occurred. The distribution of residues at this range will be unpredictable because of the uncertainty of how the soils were moved during the grading process.

5.5 40-mm New Castle Rifle Grenade Range

Only two surface composite soil samples were collected at the New Castle 40-mm range. NG, 2,4-DNT, and TNT were detected in these samples; the concentrations ranged from 87 to 222 $\mu\text{g/kg}$ (Table 3 ee). The presence of both NG and 2,4-DNT was unexpected in the impact area because these two compounds are generally associated with propellants and not often found at impact areas in concentrations greater than those compounds associated with detonations. The TNT that was found is present in the 40-mm grenades and it was not surprising to find it in the target area. The relatively low concentrations found at this range are probably due to the fact that it has only been in use for nine months and it is possible that no low-order hand grenade detonations had occurred during this period.

5.6 New Castle Hand Grenade Range

The results from the linear surface composite samples are presented in Table 3 ff. Like the 40-mm range, this range has only been in use for 9 months and the concentrations of compounds present in the surface soil were quite low. M67 hand grenades contain Composition B and thus we expected to find detectable concentrations of TNT and RDX. RDX was detected in one sample analyzed at RDDC and HMX was detected at about 25 $\mu\text{g/kg}$ in the samples collected 50 m from the throwing area.

The concentrations of residues from Composition B were much lower at this range than found at other hand grenade ranges that we have sampled (Jenkins et al. 2001). This is probably due to this being a new range that may not have had any low-order detonations occur on this site. Only very low concentrations of residues result from high order detonations of hand grenades (Hewitt et al., in press).

Like the 40-mm range, however, concentrations of NG and 2,4-DNT were found in most of the soil samples collected at this range. For NG and 2,4-DNT, concentrations ranged from 43 to 200 $\mu\text{g/kg}$, and from 6 to 61 $\mu\text{g/kg}$, respectively. These compounds are normally found on ranges due to their use in various types of propellant formulations. Since no propellants were used at this range, the reason for their presence is unknown. Whether this site had been used for other purposes prior to being converted to a hand grenade range is unknown, but seems a likely possibility. Both NCRGR and NCHGR were included in the past in the rebounding area of Argus Impact Area. This would likely explain the presence of NG and 2-4 DNT.

5.7 Hersey Impact Range

The results for the soil samples collected at the Hersey Impact Artillery Range are presented in Table 3 gg. All but one of these samples were linear surface composites collected to the east and west of the road that runs down the length of the range. One sample had a concentration of NG of 466 µg/kg and several had barely detectable levels of 2,4-DNT, but the compound found in the most samples was RDX. However, the highest concentration of RDX was only 22 µg/kg. A few samples also had detectable concentrations of TNT, and 2ADNT and 4ADNT, which are transformation products of TNT. The detection of both TNT and RDX at low levels in these samples is indicative of the impacts of Composition B rounds (possibly 105-mm) at this range.

All of the concentrations of RDX residues obtained for samples from the Hersey Range were below 25 µg/kg indicating that there is very little potential RDX groundwater contamination from this area. This is in agreement with most of the samples collected at artillery ranges where concentrations are in the low µg/kg range except near areas contaminated from low-order detonations (Pennington et al. 2003).

5.8 Lawfield Impact Range

Concentrations of energetic compounds for soil samples from the Lawfield Range were generally higher than found for the Hersey Range (Table 3 hh). The transect sample, collected from 25% of the downrange distance to the south of the centerline, had a TNT concentration of 426 µg/kg. Concentrations of 2,4-DNT, NG, 2ADNT and 4ADNT were also detected in this sample, but at much lower concentrations.

Residues of energetic materials were also found near five cratered areas in the Lawfield Range. For the first crater area, samples were collected at three depths below surface. For the 0-2-cm sample, concentrations of RDX and NG were detectable at 9.1 and 30.6 µg/kg, respectively. NG was not detectable in the samples from 2-5 cm and 5-10 cm, but RDX was detected at 10.7 and 5.6 µg/kg, respectively, due to its greater mobility in soil.

Similar results were obtained for surface samples collected in a runoff area below a cratered area; NG was detected at 37 µg/kg and RDX at 11.3 µg/kg. 2,4-DNT was also detected at 31 µg/kg in this sample.

Much higher TNT concentrations were found for composites collected inside a relatively new crater. The highest TNT concentration was 920 µg/kg, but this sample had no detectable RDX, 2ADNT or 4ADNT indicating that this area was recently contaminated by TNT rounds. Other samples in this area had detectable concentrations of TNT, RDX, 2ADNT and 4ADNT with maximum values of 332, 140, 76.7, and 83.4 µg/kg, respectively. These areas were likely contaminated at an earlier date with residues from a Composition B-filled round.

Depth samples were also collected within another crater. In these samples, RDX was detected at 114, 23.2, and 10.3 µg/kg for samples collected at 0-2cm, 2-5cm, and 5-

10cm, respectively. Concentrations of 2ADNT (11.5 µg/kg) and 4ADNT (10.4 µg/kg) were detected in the surface sample, but concentrations were below detection for the deeper ones.

In the final crater samples from Lawfield, TNT and RDX were again detected at maximum concentrations of 612 and 132 µg/kg, respectively. Overall, the concentrations of explosives residues within the Lawfield Range are somewhat higher than we have found at other artillery ranges including Ft. Lewis [22], Yakima Training Center[22], or other ranges at the Gagetown training area discussed here.

Finally, two samples were collected next to 105-mm UXO rounds at Lawfield. For one round, the sample contained an RDX concentration of 20.8 µg/kg, but we are unable to say whether this low RDX concentration was from the UXO round or from another source on range. The lack of detectable TNT, 2ADNT, and 4ADNT implies that the contamination is not from recent leakage from a Composition B-filled 105-mm round.

5.9 Argus Impact Area

As was mentioned earlier, the Argus Impact area had been the site for a major live fire exercise named *Staunch Gladiator* two weeks before our sampling campaign. As a result of this and other firing events, TNT was detected in most samples collected from this range (Table 3 ii). RDX, on the other hand, was only detectable at a significant concentration in one sample, indicating that the most contaminating rounds fired at Argus are TNT-containing ordnance. Except for two samples collected near crater 2, concentrations of 2ADNT and 4ADNT were below detection limits indicating that the TNT concentration found on this range must be relatively fresh or a greater portion would have transformed into these transformation products.

The concentrations of TNT in surface soil samples around two targets and in a large open demolition crater were generally about 100 µg/kg. The concentrations around several bomb craters (craters 2-4), however, were much greater, ranging from 17,600 to 4,220,00 µg/kg. As mentioned earlier, the standing water that had collected in crater 4 was reddish-orange in color probably due to phototransformation of TNT. Upon analysis, the concentration of TNT in water collected from this crater was about 20,000 µg/L.

Overall, the TNT concentrations in surface composite samples from the area around crater 4 averaged about 3,000,000 µg/kg, an order of magnitude greater than samples collected around crater 2, which had concentrations about an order of magnitude greater than the area around crater 3. Apparently, these bombs did not undergo a complete detonation, leaving substantial residues in and around these bomb craters.

Soil samples were also collected around two 2.75 inch rocket craters (craters 5 and 6). The concentration of TNT in one of these surface samples was 596 µg/kg. HMX was also detected in these two samples at 37.4 and 39.0 µg/kg, but RDX was below 5 µg/kg in both samples.

Overall the concentrations of explosives residues at the Argus range are much higher than normally found on artillery ranges. The higher concentrations were generally for TNT and may be related to the use of this range for bombing as well as artillery when large combined fire exercises are conducted at Gagetown. With respect to the potential for ground water contamination, RDX is the major compound of concern due to its much greater tendency to leach and its low regulatory limit in drinking water. The RDX concentrations for most of the samples from this range were below detection and hence no major ground water contamination source for RDX was identified.

5.10 Greenfield Impact Range

Analyses of soil samples from the Greenfield range are presented in Table 3 jj. As pointed out above, the Greenfield range is located between the Hersey and Argus impact ranges and serves as a "ricochet" range for rounds fired at the Hersey, Argus and Anti Armour ranges.

Linear composite soil samples at 40% and 60% were analyzed. One sample had a concentration of TNT of 134 µg/kg. RDX was detected in several of these samples, but concentrations were 25 µg/kg or below. HMX, NG and 2,4-DNT were detected in one or more of these samples, but concentrations were generally below 60 µg/kg.

5.11 Burning Area

The results of analysis of samples collected at several burning areas are given in Table 3 kk. 2,4-DNT was detected in all of these samples with concentrations ranging from 148 to 31,600 µg/kg. Apparently the majority of the burning activity was for single-based propellant bags. Other target analytes detected in these samples were 2,6-DNT, TNT, RDX and tetryl. No NG was detected in any of these samples. This was the only set of samples collected at Gagetown in which tetryl was detected. It should be emphasized that several of these samples contained visible amounts of unburned propellant, left over from the destruction process.

6. Results and Discussion – Metals

6.1 Background Samples

Background soil and biomass samples were collected in order to assess the extent of the anthropogenic contribution of metals to the training ranges. For biomass, no guidelines are published in relation to metals contamination, so results are compared to the mean background (MBG). For soils, MBG is still considered as a good comparison tool, but CCME provides quality guidelines for agricultural soils (ASQG), which is the base of comparison for the results. All results discussed in the following section are presented in table 4 for both soil and biomass (See attached CD).

6.1.1 Biomass BG Samples

Thirteen biomass BG samples were collected at various locations. One of those, identified by B-BG-17385-70972, was duplicated. The parameters analyzed in biomass were the following: Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Rb, Sb, Se, Sn, Sr, Te, Tl, U, V and Zn. The Mean Background (MBG) level was calculated by adding the average concentration of the samples to twice the standard deviation. In the background samples, 21 values slightly exceeded the MBG, so those values contributed to an increase in the MBG level. The values are highlighted in red in the table. It is interesting to note that 10 out of those 21 values were found in the same sample, which is B-BG-03678-79720. This particular sample was collected downwind of the Old Castle grenade range, which may explain the higher levels encountered. However, the soil sample collected in the same area did not show any higher trends. This location and locations nearby will be re-sampled in the fall to confirm the higher levels detected

6.1.2 Soil BG Samples

Fourteen soil samples, four of them duplicated, were collected at various locations around the training area and in almost the same locations as the biomass samples. The parameters analyzed for soil samples were the same as for biomass samples, with the addition of Hg. The MBG was also calculated according to the same equation, but, when available, the CCME ASQG was noted in the table. Values exceeding the MBG were highlighted in red. Sixteen values slightly exceeded the MBG, found mostly in samples S-BG-12879-78123 (5), S-BG-03737-65708 (3), S-BG-97286-74154 (2), S-BG-MCALPINES-2SACS (3) and S-BG-HARTS (3). No values exceeded the ASQG in BG samples, since the level is more permissive and that the MBG is made of an average of all samples coming from the same area, which contributes to lower the average and standard deviation, thus the MBG.

6.2 Anti-Armour Range

Four biomass samples (plus one duplicated) and 28 soil samples (plus one duplicated) were analyzed. The details are presented in the next two paragraphs.

6.2.1 Biomass AA Samples

For biomass samples, the sampling method used was linear transects at 20 and 40% of the range. Two of the samples were collected on the eastern part of the centreline, whereas the other two were collected on the western part. Comparison was made with the MBG, and 13 values exceeded this level. They are found in red in the table. The two most exceeding parameters were Bi (4 out of the 5 samples exceeded) and Pb (all 5 samples exceeded). The other exceeding parameters were Cu, Sb, Sr and Te. Sample B-AA-LS-40%A contained 5 out of the 13 exceeding values.

6.2.2 Soil AA Samples

Soil samples were collected according to all methods described in Section 4.2. Seven composite samples were taken in front of firing position number 4, at 0, 10, 20, 30, 40, 50 and 100 m from the firing position. Eight composite samples were collected along linear transects at 20, 40, 70 and 100% of the range. The other 13 samples were collected around tank targets 1, 2 and 3. Results that exceeded MBG, but were less than ASQG, were highlighted in red, whereas values that strictly exceeded ASQG (and MBG implicitly), were highlighted in blue. A total of 192 values exceeded MBG. The greatest exceedance was by Ca, which exceed the MBG by an order of magnitude. The main parameters that exceeded MBG were Ag (8), B (11), Ba (10), Ca (8), Cu (15), Mo (16), Pb (13), Sb (21), Sn (10), Tl (10) and Zn (8). Forty-three values exceeded not only MBG, but also ASQG. Principal parameters of concern were As (2), Cd (7), Cr (2), Cu (12), Ni (4), Pb (12) and Zn (4). The following samples, which contained a significant number of parameters exceeding ASQG, are of particular concern: S-AA-T1-ARRIERE (5), S-AA-T2-AVANT (6) and S-AA-T2-ARRIERE (6). In general, we could tell that high levels of copper (Cu), Molybdenum (Mo), Lead (Pb), Antimony (Sb), Strontium (Sr) and Zinc (Zn), are the characteristics of the Anti-Armour Range. Ten soil samples showed levels of Cu or Pb even higher than the CCME Industrial Soil Quality Guideline (ISQG). These metals can have a significant impact on the environment. Also, it seems obvious that the samples collected around the targets show more contamination than the others, due to the detonation of the munitions. The following parameters were detected over MBG in both soils and biomass: Pb, Cu, Sb and Sr.

6.3 Wellington Anti-Tank Range samples

Only one composite biomass sample and 11 soil samples were analyzed for Wellington Anti-Tank Range. However, the results demonstrated a trend in the contamination.

6.3.1 Biomass WAT Sample

The only biomass sample collected was a composite created by mixing samples that were collected around targets 1 and 2. Out of the 31 parameters analyzed, 19 exceeded the MBG (highlighted in red in the table). Bi and Cu exceeded MBGs by two orders of magnitude, and Ag, Cd, Cr, Pb, Sb, and Sn exceeded MBGs by one order of magnitude. Since only one biomass sample was taken, no comparison can be established with other parts of the range. However, the biomass in WAT range is certainly contaminated by various metals at one or two order of magnitude over the MBG.

6.3.2 Soil WAT Samples

Soil samples were collected around targets 1 to 5, around firing position and at the OD pit. At first glance, samples collected around the targets showed more contamination than at the firing position, which is obviously caused by the detonation. In this series of samples (around targets), Cd, Cu, Pb, and Zn exceeded ASQG in all 8 target samples, while Cr and Ni exceeded ASQG in 5 out of the 8 target samples. Cu, Pb and Zn results were by far the most important, since the majority of them exceeded ASQG by at least one order of magnitude. Cu, Zn and Pb results also exceeded the ISQG in all samples around target tanks. The other important parameters were Ag, Bi, Mo, Sb, Sn (all 8 target samples exceeded MBG), Ba (7 out of the 8 target samples exceeded MBG), B, Sr (5 out of the 8 target samples exceeded MBG), Ca, Fe, K, Na, Tl and U. For the other series of samples, which were around the firing position and at the OD pit, no major contamination was detected. The most contaminated firing position sample was S-WAT-FP-BACK, with 10 out of the 32 parameters exceeding MBG. Two of those exceeding parameters, B and Sn, exceeded MBG by one order of magnitude. Those results indicated that EM was sprayed behind the gun after shooting the munitions. Parameters found both in soils and biomass were Ag, Bi, Cd, Cr, Cu, Fe, Ni, Pb, Sn, Tl, U and Zn. Strangely, we obtained hits for uranium in both soils and biomass, while no record of the use of uranium-based ammunitions were available for this range.

6.4 Old Castle Grenade Range samples

Five biomass samples and six soil samples were analyzed. Due to the previous decommissioning of the range and disturbing of the soil profile, no major contamination was discovered.

6.4.1 Biomass CGR Samples

All five samples analyzed showed results exceeding MBG. In total, 51 parameters exceeded the mean background level, the most important being Zn (all samples), Cd (4 out of the 5 samples), Bi, Mo, Na, Te (3 out of the 5 samples), Al, As, Be, Co, Cr, Cu, Fe, Li, Mg, Ni, Tl, U and V (2 out of the 5 samples). The most contaminated samples were B-CGR-MIDDLE and its duplicate, with 34 exceeding parameters out of the 51. Those results indicated that most of the contaminants are found in the middle of the range, where the majority of the grenades were fired.

6.4.2 Soil CGR Samples

Results for CGR soil samples were well distributed. First, the most important parameter was Zn again, where all samples exceeded ASQG. The other parameters that had to be taken into consideration were Cd and Cu (5 out of the 6 samples exceeded MBG, and the other sample also exceeded ASQG, along with Sr (all samples exceeded MBG), Sb, Sn (4 out of the 6 samples exceeded MBG), and Ca, As, Ba, Ni and Pb. The most contaminated sample was S-CGR-CORE-5-10 CM, with 9 parameters exceeding MBG, including 2 parameters that also exceeded ASQG. (Zn exceeded ASQG by one order of magnitude). These results showed that contaminants were mainly found in deeper layers of the soil. The further migration of these contaminants in the aquifer could lead to human adverse impacts. The following metal analytes were found in both media: As, Cd, Cu, Ni, Sn and Zn.

6.5 New Castle Rifle Grenade Range Samples

Two biomass and two soil samples were collected and analyzed. The range being very recent and less firing activities occurring there, no major contamination was detected with only two soil samples showing higher levels of Sr than MBG.

6.5.1 Biomass NCRGR Samples

One biomass sample was taken at the left of the range another was collected behind target 1. In these two samples, a total of 14 parameters exceeded MBG, the most important being Bi, Cu, Pb, Sn and Zn (both samples exceeded MBG), Ag, Cd, Mo and Te. Sample B-NCRGR-LEFT showed

more contamination, with results 4 times greater than the MBG for Cu and Zn.

6.5.2 Soil NCRGR Samples

Only two parameters slightly exceeded MBG, both related to Sr. This result may be attributed to the presence of strontium in 40-mm rifle grenades.

6.6 New Castle Hand Grenade Range (NCHGR) Samples

Three biomass and seven soil samples were analyzed. Again, the contaminants were very well distributed, which facilitated the interpretation of the results.

6.6.1 Biomass NCHGR Samples

Twenty parameters exceeded the MBG levels. The greatest were Cd, Cu, Pb, Zn (all three samples), Na (2 out of the 3 samples), B, Bi, Mg, Rb, Sb and Te. The most contaminated samples were B-NCHGR-RIGHT and its duplicate, which exhibited 16 of the 20 parameters. Again, zinc was the metal that seemed to accumulate the most in this area.

6.6.2 Soil NCHGR Samples

In the seven samples analyzed, 3 parameters gave significant results. The first one was Zn with 6 samples exceeding ASQG and the other one exceeding MBG. The second important parameter was Cu, where 6 samples exceeded MBG and the other exceeded ASQG as well. The final parameter was Sb, where 6 samples slightly exceeded MBG. The most contaminated sample was S-NCHGR-10M, where the concentration of zinc was exceeded 3 times the ASQG. Such results are understandable, since this sample was collected close to the bunker wall, where most of the grenades are fired. Even if this range was recently built, many trends of metal accumulation could be measured.

6.7 Hersey Impact Range Samples

Sixteen biomass and sixteen soil samples were analyzed. No significant contamination seemed to have occurred there, but some results are still highlighted.

6.7.1 Biomass H Samples

Sixteen composite biomass samples were collected along linear transects to the left and right-hand sides of Hersey Road, from 40 to 100% of the distance from this road. A total of 36 parameters exceeded MBG. No samples greatly exceeded the MBG level, except Al and Fe, where the concentration was more than twice the MBG. The most important parameters were Te (8

samples), Cd (4 samples), Rb (3 samples), Pb, Sn, Tl (2 samples), Ag, As, B, Be, Bi, Co, Cr, Cu, Li, Mo, Sb, U and V. The most contaminated sample was B-H-LS-80%B, with 15 out of the 36 parameters exceeding ASQG. This result could indicate that most of the detonations happen in this transept, leading to a measurable pattern for metal dispersion.

6.7.2 Soil H Samples

In the sixteen samples analyzed, only two parameters exceeded ASQG, one for Cd and one for Zn. Cd (11 samples), Cu (12 samples), Sr (6 samples), Zn (5 samples), Ag, K, Pb (3 samples each), Ba, Ca, Mn and Rb (2 samples each) exceeded MBG only. In general, the concentrations did not greatly exceed MBG, so we can conclude that the area is not highly impacted.

6.8 Lawfield Impact Range Samples

For Lawfield Impact range, 10 biomass and 14 soil samples were analyzed. Soil samples consisted of composite surface samples around impact crater clusters and composite surface samples at 25% of overall length of the range, either side of the centreline. Biomass samples were collected in the same manner.

6.8.1 Biomass L Samples

A total of 62 parameters exceeded MBG, the two most important being Cd and Zn, where all samples exceeded the MBG levels. The other important parameters were Cu (exceeded MBG in 7 out of the 10 samples), Pb (6 samples), Ag (5 samples), Al, Bi, V (3 samples each), Co, Cr, Fe, Li, Ni, Sn (2 samples each), Be, Mo and Tl. The most contaminated samples were B-L-HS-13930-69376 and its duplicate, which exceeded 28 of the 62 parameters. Those samples were collected around impact craters and close to UXO's, which indicate a localized impact of the UXO presence. The field duplicate showed similar results indicating good field reproducibility.

6.8.2 Soil L Samples

Results of the soil sample analyses were very similar to those of the biomass sample analyses. First, almost no values exceeded ASQG; in fact, the only two values that exceeded ASQG were values for Cu, which barely exceeded ASQG (values were 64 and 67 ppm). As for the biomass samples, the most important parameters were Cd and Zn (exceeding MBG in 12 samples out of 14 samples), but also Cu, where all samples exceeded MBG. Besides that, only the following parameters exceeded the MBG values: Ba, Mo, Pb, Sb, Sn, Sr and V. The most contaminated sample was S-L-HS-13952-69466, which contained the highest concentration of Cu (67 ppm) and Zn (170 ppm). This sample was also collected around impact craters and UXO's.

6.9 Argus Impact Area Samples

For Argus Impact area, 19 soil and one biomass sample were analyzed. Despite the intense use of this training area, no major contamination was detected.

6.9.1 Biomass AR Sample

In the sole biomass sample analyzed, 14 out of the 31 parameters exceeded MBG. Those parameters were Al, As, Be, Bi, Co, Cr, Fe, Li, Ni, Pb, Sb, Tl, U and V. The most critical ones were Pb, which exceeded MBG by one order of magnitude, and Al, which exceeded MBG by 2.5 times. The sample was collected to the left of target 1.

6.9.2 Soil AR Samples

Fifteen soil samples, which were collected around 6 different craters, were analyzed, and the four other samples came from targets 1 to 3. In general, for the samples collected around craters, cadmium was the most considerable parameter, where 11 out of the 15 values slightly exceeded MBG. Some other parameters presented exceeding values, such as B, Cu, K, Sn, Sr and Tl. More contamination was found in the four samples that were collected around targets 1 to 3. For example, two out of the four samples presented values that exceeded ASQG for Cu. Also, Pb exceeded ASQG in 3 samples, while Cd, Tl and Zn exceeded ASQG in one sample, which was S-AR-T2-FRONT. This sample was by far the most contaminated, since copper and zinc exceeded ASQG by one order of magnitude, and lead exceeded ASQG by two orders of magnitude. Many other parameters exceeded only MBG: Ag, As, Ba, Be, Bi, Ca, Co, Cr, Fe, K, Mg, Mo, Ni, Sb, Sn, Sr and Tl.

6.10 Greenfield Impact Area Samples

Four soil and four biomass samples were collected along linear transects at 40 and 60% of the overall length of the range, on either side of the centreline. The results showed almost no contamination.

6.10.1 Biomass GF Samples

Only three parameters slightly exceeded MBG Ag, Sb and Sr. None of those parameters greatly exceeded the level, so we can conclude that contamination was minor. Sample B-GF-LS-60%B contains 2 out of the 3 parameters.

6.10.2 Soil GF Samples

Only four parameters, all part of the same sample (S-GF-LS-60%B), slightly exceeded MBG, Ag, B, Ba and Pb. The most contaminated soil sample was co-located with the most contaminated biomass sample. Therefore, we can conclude that this area of the range was possibly more contaminated than elsewhere.

6.11 Small Arms Ranges and Burning Locations

Some samples were collected in small arms ranges, such as Batouche, Reichwald and Vimy and also in two gun propellant burning locations named Airstrip and Lawfield. Only soil samples were collected. Some high levels of contamination were found.

6.11.1 Batouche Range

Five composite soil samples were collected in Batouche Range, covering targets 1 to 12. All five samples presented exceeding values, in the following way: Cu and Pb (exceeding ASQG by one order of magnitude for Cu, two orders of magnitude for Pb, except in sample S-BATOUCHE-12 DEPTH, where Cu slightly exceeded ASQG and Pb exceeded ASQG by one order of magnitude), Sb, Sn, Sr and Tl (all exceeding MBG by one or two orders of magnitude). Some other parameters exceeding MBG in all samples except S-BATOUCHE-12 DEPTH, were Ag, Bi, Te and Zn. Other significant parameters were As (exceeding MBG in 2 samples), K (1 sample), Mo (2 samples) and Na (3 samples). The most contaminated sample was S-BATOUCHE-5-8, with the highest values of Cu (818 ppm) and Pb (21500 ppm).

6.11.2 Reichwald Range

Seven composite soil samples were collected for targets 1 to 20. The sample at target 1 was collected to a depth of 0-5 cm and was duplicated. Since no contamination was detected in the samples collected at depth, we can conclude that contaminants usually reside at the surface. For the five samples that were collected in surface around targets 1 to 20, high levels of Cu and Pb were found (exceeding ASQG by one or two orders of magnitude). Also, values for Ag, Sb, Sn and Tl exceeded MBG in those five samples. The other parameters were Bi (exceeding MBG in 4 samples), Sr (4 samples), Te (4 samples) and Zn (4 samples, including a value that also exceeded ASQG). The most contaminated sample was S-REICHWALD-13-16, showing the highest concentrations of Cu (1860 ppm), Pb (17000 ppm) and Zn (218 ppm).

6.11.3 Vimy Range

Four composite soil samples were collected around targets 1 to 12 and in depth at target 1. All four samples exceeded ASQG in Pb, and 2 out of the 4 samples exceeded ASQG in Cu (the two other samples exceeded only MBG). The other parameters were Ag (exceeding MBG in one sample), As (1 sample), Bi (1 sample), Ca (2 samples), K (1 sample), Na (all 4 samples), Sb (all 4 samples), Sn (all 4 samples), Sr (3 samples), Te (1 sample), Tl (2 samples) and Zn (1 sample). The most contaminated sample was S-VIMY-9-12, with high concentrations of Cu (379 ppm) and Pb (13500 ppm), along with 11 other parameters that exceeded MBG.

6.11.4 Airstrip Burning Location

Three soil samples were collected at burning location Airstrip 2. High levels of lead were found in all three samples, and all exceeded ASQG by an order of magnitude. Copper (Cu), Antimony (Sb) and Strontium (Sr) also showed values exceeding MBG in all three samples. Other parameters were B, Bi, Sn and Tl. Cu and Pb were the most common metals found in this burning location. This is in keeping with the lead used in artillery propellants as a lubricating agent.

6.11.5 Lawfield Burning Location

Three soil samples were also collected in Lawfield burning location. Again, Pb exceeded ASQG by one order of magnitude in one sample, and by two orders of magnitude in the other samples. Strontium also showed values that greatly exceeded the MBG in all three samples. Other parameters exceeding MBG or ASQG were Ba, Mn, Sb, Sn, Tl and Zn.

7. Conclusion and Recommendations

7.1 Metals

The average and standard deviation was calculated for all background samples site wide. The mean background (MBG) level was calculated by adding the mean value to twice the standard deviation. This served as the basic comparison level, when no other criteria were available, such as for metals concentrations in biomass and in most of the agricultural soils. Results that exceeded only these MBG levels were highlighted in red in all tables, while results that also exceeded ASQG were highlighted in blue. In this manner, no results were highlighted in blue for biomass, since no criteria exist. Although based on an insufficient number of background samples for statistical comparisons, these data are highly interesting for observing contaminant trends in the live fire area.

The most common metals found in biomass were cadmium (Cd), lead (Pb) and zinc (Zn), especially in the grenade ranges and in Lawfield range. In soil samples, the most common metals were almost the same: cadmium, copper (Cu), lead and zinc. The areas of primary concern are Anti-Armour Range (AA), Wellington Anti-Tank Range (high levels of copper, lead and zinc), all of the grenade ranges for their high concentration of zinc, and all of the small arms ranges for their high concentrations of copper and lead.

More particularly for the Anti-Armour Range, 21 parameters in soils exceeded MBG with Cu, Mo, Pb, Sb, Sr and Zn being the most predominant. Four parameters were detected in both soil and biomass samples Pb, Cu, Sb and Sr. Highest concentrations were found around targets. The following parameters were found in concentration over either the ASQG or the ISQG: Cd, Cr, Cu and Pb.

In Wellington Antitank Rocket Range, high levels of various metal analytes were detected in soils both at the target locations and to the front and rear of the firing position. Many parameters were detected in both soils and biomass including Uranium, which might indicate a past use of this metal on the range. The following parameters were detected around targets at levels above the ASQG or the ISQG: Cd, Cu, Cr, Pb and Zn.

So both in Anti-Armour Range and in Wellington Antitank Rocket Range, we observed an accumulation of high concentrations of heavy metals in both the target areas and firing positions. Greater levels of heavy metals and Ca, Na, and K are also found in the biomass samples. More biomass samples are needed in WAT to confirm the high results obtained.

The three grenade ranges sampled were impacted by various heavy metals. The oldest (Old Castle Grenade Range) was the most impacted. Both soil and biomass showed a

pattern of multiple contaminants and the greatest concentrations were detected for Cd, Cu and Zn.

Metals are also detected in high concentrations at target areas or in craters in artillery impact areas. The contaminants of concerns in the artillery ranges are Cd, Cu and Zn. Argus impact area is the range presenting the most elevated concentrations of metals followed by Lawfield, Hersey and Greenfield Impact Areas.

In small arms ranges, various analytes were found in high concentrations in the firing butt. Lead is the primary contaminant of concern with values as high as 21,500 ppm. High values were observed in all samples collected. High levels of Na, Ca, Mg and K were found in the same samples. These salts might attract grazing wildlife. Other metal analytes found in high concentrations were Cu, Sb, Sn, Sr, Tl and Zn.

The burning area presented high concentrations of Pb and Sr with levels as high as 7,060 and 3,905 ppm, respectively.

In general, trends that were identified for soil accumulation were correlated with biomass results, where elevated metal analytes were found in both. This is mostly done by phyto-accumulation of metals, since plants are known to have the potential to concentrate contaminants in their tissues. Results for biomass were obtained only on the stem and leaves, since no roots were collected. Roots are known to bioaccumulate metals to a greater extent than stems and leaves, so results may have been higher if roots were sampled as well. The results for biomass are of concern since in many of these ranges, Na, Ca and K were also detected at elevated concentrations were also higher combined with heavy metals. This was observed as well in the Shilo training area. This may attract wildlife to preferentially graze on the contaminated biomass.

7.2 Energetic Materials

Both Anti-Armour Range and in Wellington Antitank Rocket Range had concentrations of NG and 2,4-DNT to the front and rear of the firing positions, with concentrations up to % levels in surface soils behind the firing position of Wellington. These residues are related to the use of single- and double-base propellants. Results found at the Anti-Armour Range were similar to those found on a US range (Yakima Training Center). The same contaminants were also found down range at Wellington, probably as a result of rocket fuel (propellant) that is distributed at the detonation point. TNT and RDX were found near targets at the Anti-Armour Range at various concentrations less than 5 ppm. Concentrations of RDX and HMX were higher near target 3. A possible explanation for the higher levels near target three is the blow-in-place of UXOs or a partial detonation of a Comp B filled munition. At Wellington, concentrations of HMX far exceeded those of any other energetic compounds in the impact area near targets. The HMX likely originated with the use of Octol-based M72 shoulder antitank rockets on the antitank ranges. High concentrations of HMX and TNT were also detected in deeper soil samples, with HMX detected at concentrations up to 932,000 ppb for one core sample. This trend will be further investigated in the future. when more core samples will be collected.

In the grenade ranges we found a pattern of concurrent contamination by TNT, TNT derivatives and RDX, with the oldest range (Old Castle Grenade Range) being the most concentrated. These residues are indicative of Composition B filled grenades used on these ranges. Results obtained are similar to those found in other Canadian and US grenade ranges. In both new ranges (NCHGR and NCRGR), NG and 2,4-DNT were also detected, which is somewhat unusual for grenade range. These later compounds might be there because of an unknown past use of the area or because of burning of excess propellant at these locations. The two newest ranges will be re-sampled in the fall 2003 to assess the build up of energetic residues. By knowing how many rounds were fired between each sampling, we might even be able to estimate a yearly source term for both ranges.

Results from the four artillery impact areas varied greatly in explosive residues. Hersey and Greenfield presented both low concentrations and spatially distributed contamination primarily by RDX, but with NG and 2,4 DNT. Lawfield presented higher concentrations of TNT, RDX and amino-DNT near craters. The concentrations detected in Lawfield were somewhat higher than found in similar ranges in the US. Argus had the greatest quantities of energetic residues. TNT was detected in all samples from this range, while RDX was detected in only one sample. Locations sampled on the Argus range therefore, were more likely to have been impacted by detonations of munitions filled with TNT as compared to Comp B. One crater from a low-order air to ground bomb presented very high concentrations of TNT, both in the soil and in surface standing water. The high results found in Argus might be explained by the prior Staunch Gladiator exercise and also by dual use of Argus for artillery and air to ground bombing. The Staunch Gladiator exercise involves both surface to surface and air to surface artillery and bomb military capabilities from several nations

2,4-DNT was detected in all samples at relatively high concentrations. Since no NG was found, mostly single base propellant must have been burned there. Other target analytes were also detected such as 2,6-DNT, TNT and RDX.

General conclusions are that the Anti-Armour Range and Wellington Antitank Rocket Range are impacted by various heavy metals and explosive residues both at level of concerns. The most contaminated areas were found near targets, and to the front and rear of firing positions. Artillery ranges were mainly impacted by Cd, Cr, Zn and Pb. Explosive residues were detected at lower concentrations on artillery ranges than on the Anti-Armour Range and Wellington Antitank Rocket Range. Grenade ranges also present mixed contamination by both metals and energetic materials with the oldest range being the highest impacted area. The burning area present high concentrations of Pb, Sr and 2,4, DNT as expected, since burning of propellants is known to be an incomplete process that leads to the accumulation of propellant residues in the environment. Finally, Small Arms Ranges firing butts are heavily impacted by lead and other heavy metals as found in Shilo SARs.

Recommendations

More sampling should be conducted in the fall of 2003 to complete the datasets and answer the question posed in this report. A relationship should be established between

the surface soils-biomass and groundwater results to determine whether vertical and horizontal migration of the contaminants is occurring at the training area. Finally, a site risk assessment should be conducted when all results are obtained to identify any potential adverse impact on human health resulting from the anthropogenic contaminant contribution of the firing activity.

8. Figures



Figure 1. Gagetown Area Map

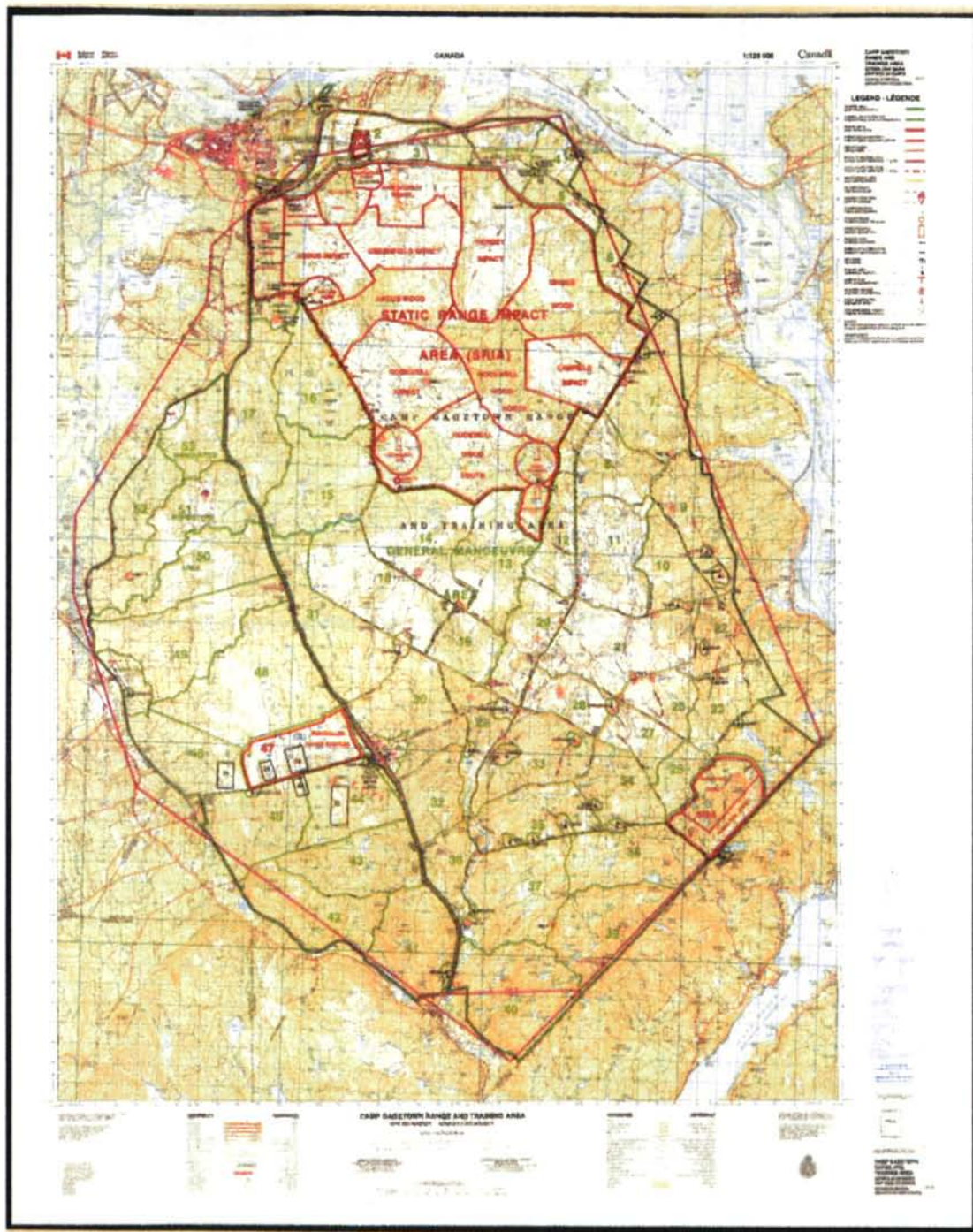


Figure 2. Gagetown Training Area Map

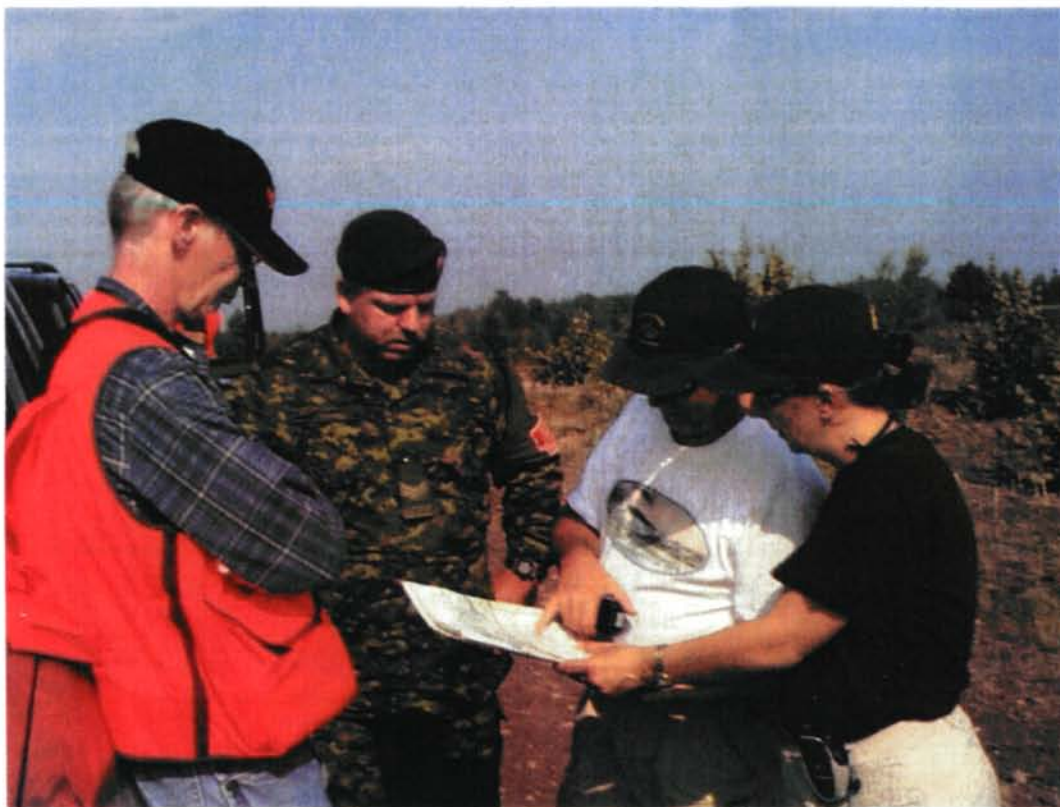


Figure 3. Establishment of the Sampling Strategy to be Used in the AA Firing Range



Figure 4. Surface sampling team

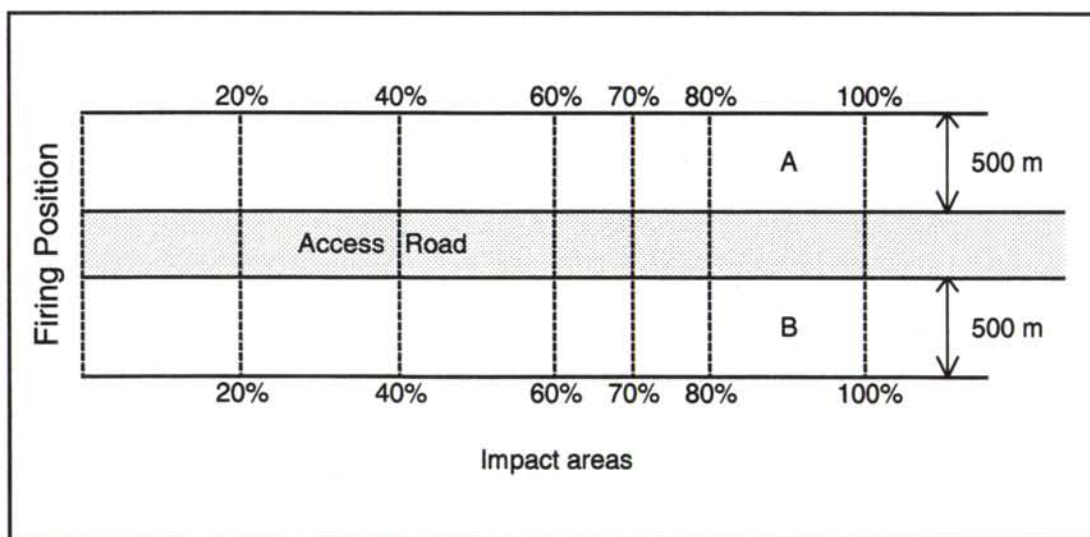


Figure 5. Linear Transept Approach

A and B represent the half portion of the range for compositing

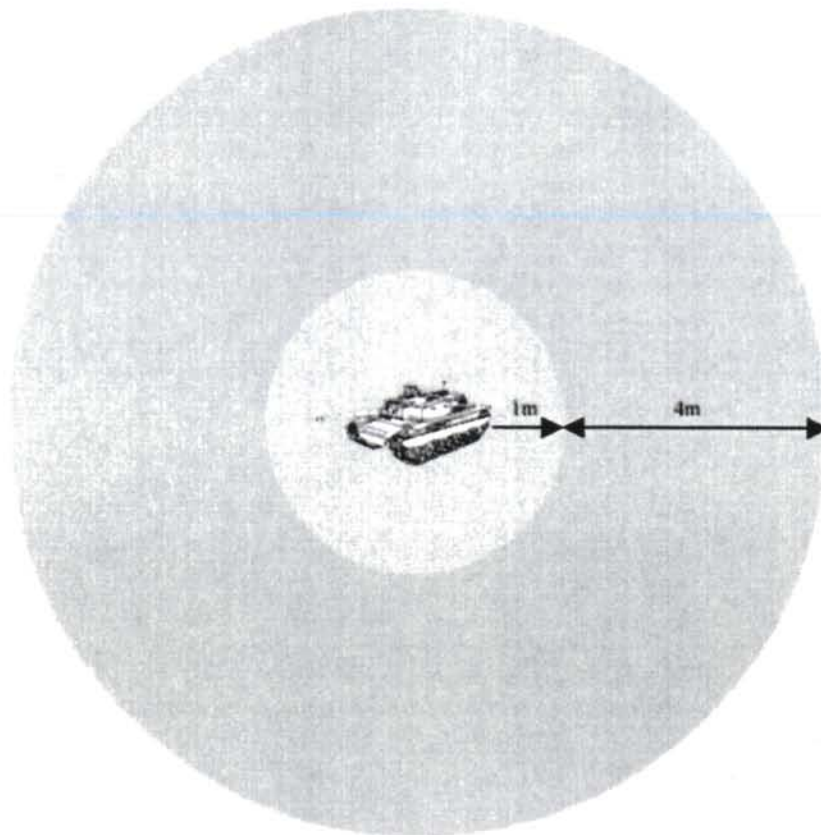


Figure 6. Circular sampling around targets

Surface soil composite samples (30 increments) were collected around the target at 1 and 4 m

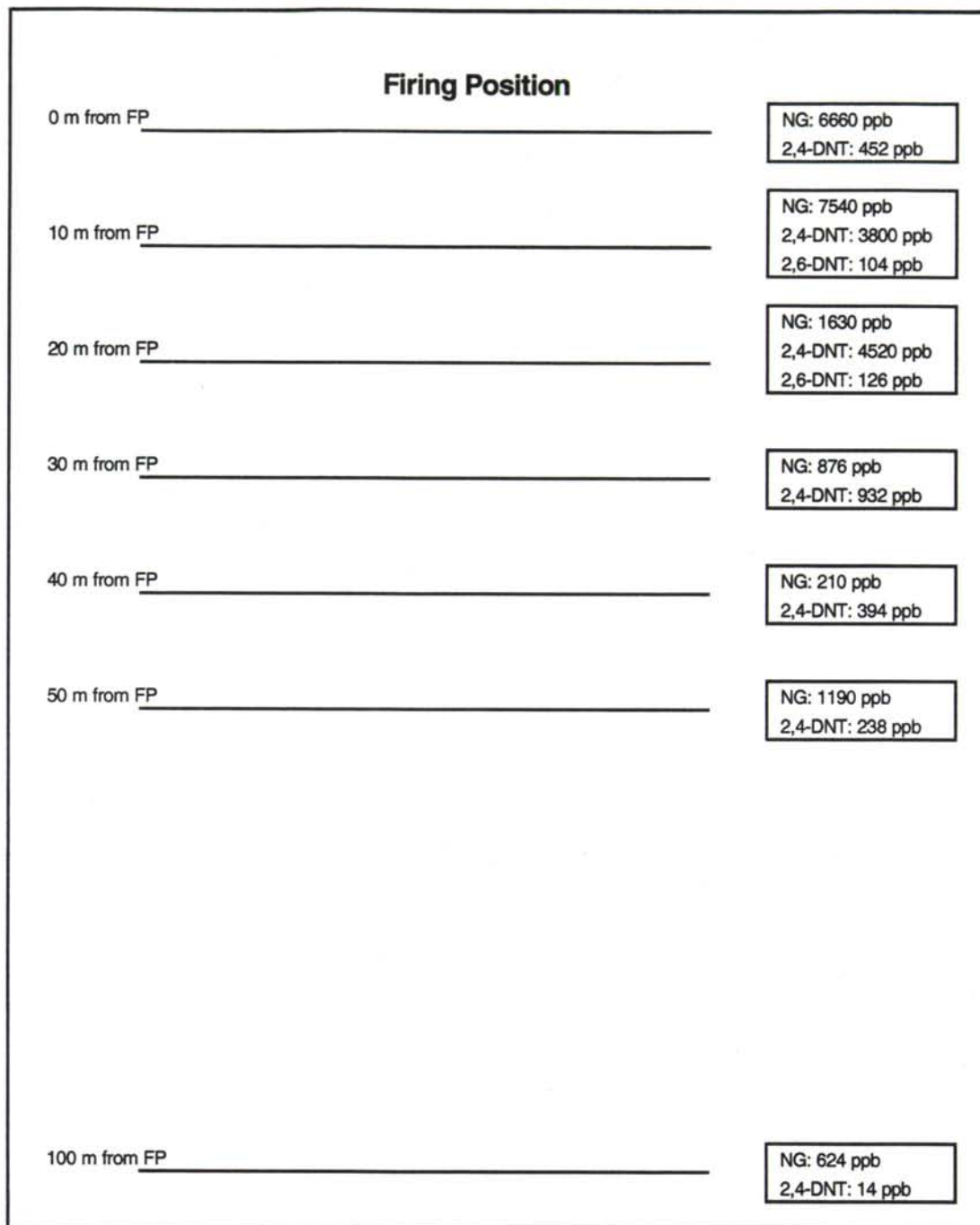


Figure 7. Linear sampling pattern used in firing position of Anti Armour range



Figure 8. Core Sampling with Manual Augers



Figure 9. Overview of the AA Landscape with Middle Access Road



Figure10. Sampling Near Target Tank 1, AA range



Figure 11. Surface Sampling Around Target Tank 2, AA range



Figure 12. Expray Field Testing on a Cracked UXO Content, AA range

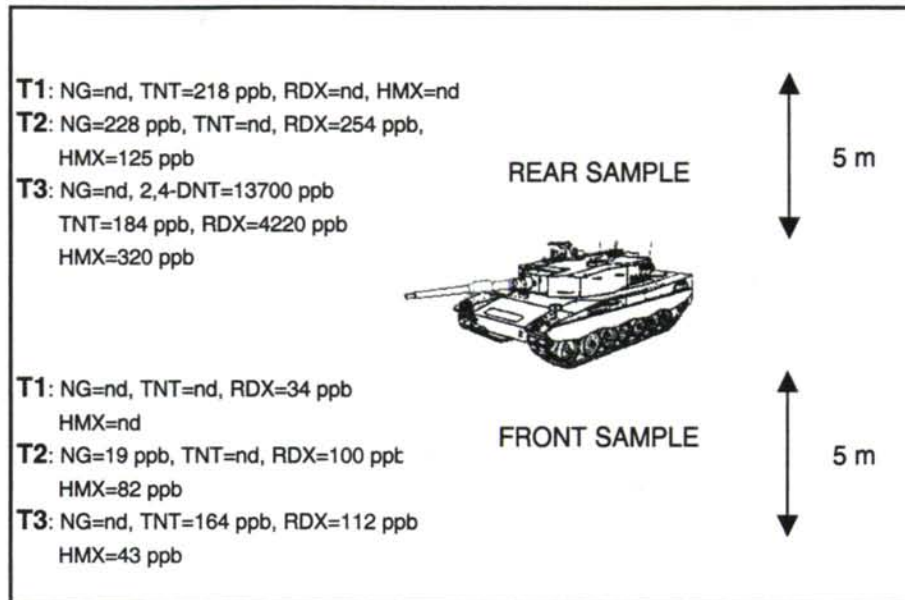


Figure 13. Sampling Pattern in Front and Rear of Targets, AA range

Surface soil composite samples (30 increments) were collected along a 5-m transect to the front and the rear of each of the 3 targets at AA range. Schematic diagram represents the sampling pattern for targets number one to number 3 (T1 to T3)

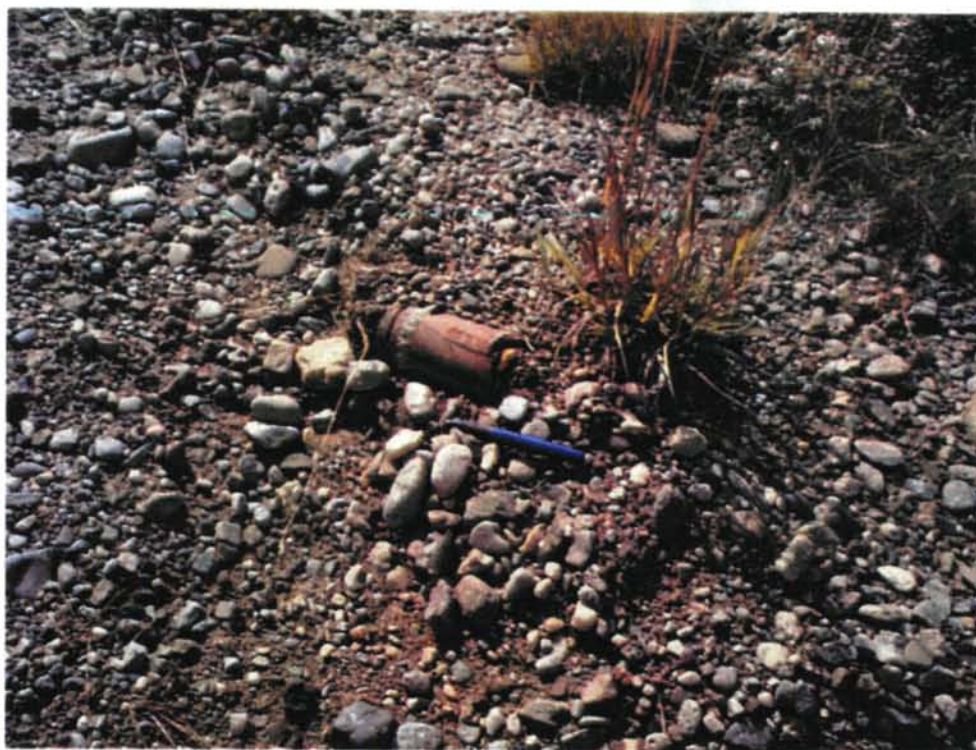


Figure 14. Dry runoff channel in Front of Target 1, AA range

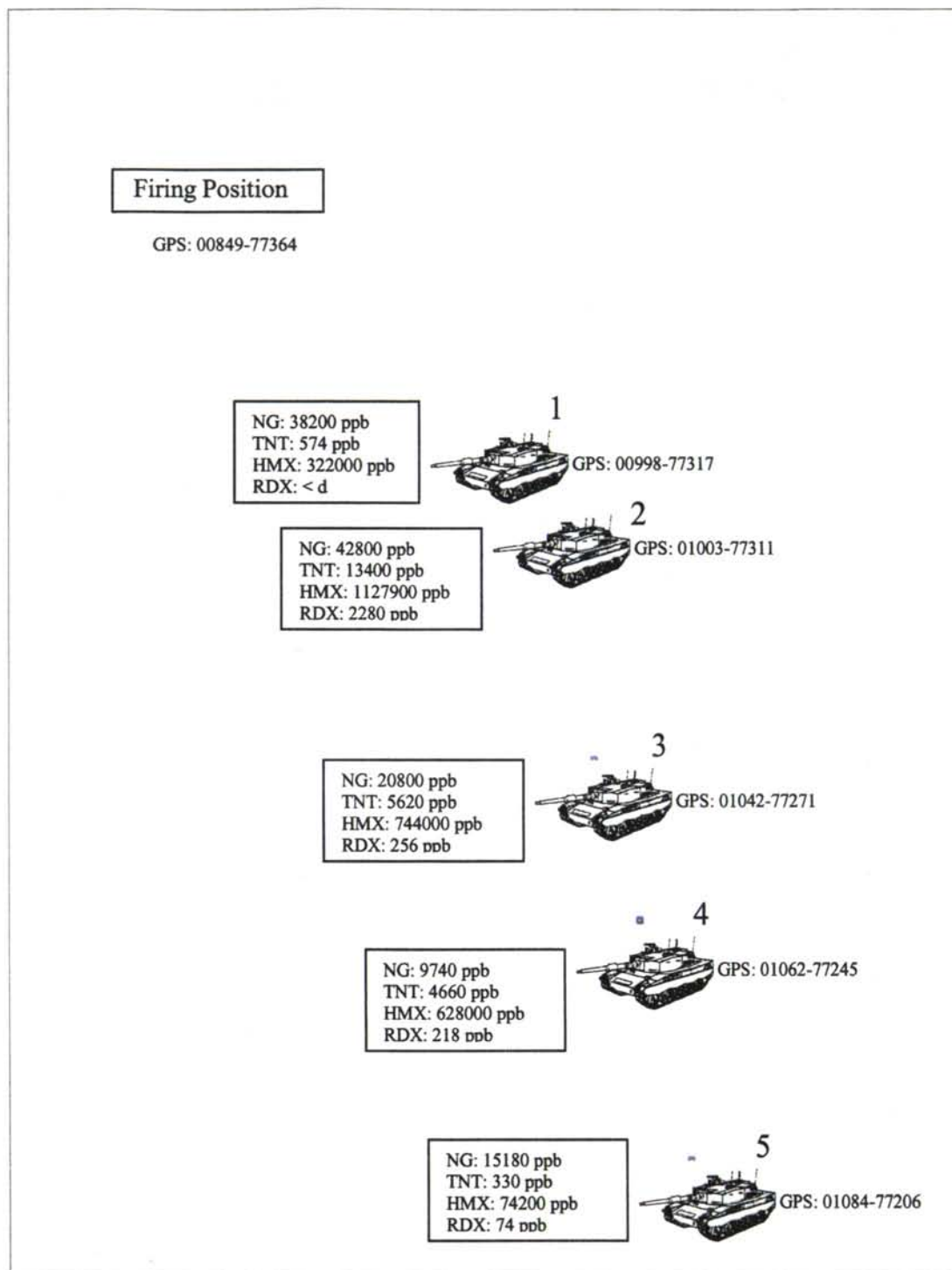


Figure15. Positions of targets 1 through 5 at the WAT range. Surface soil concentrations of explosives and global positioning coordinates give for each target location and firing point.



Figure 16. UXOSchrapnal, WAT range



Figure 17. Target 5, WAT Range



Figure 18. Target 1, WAT Range



Figure19. Sampling in Front of Target 1, WAT Range

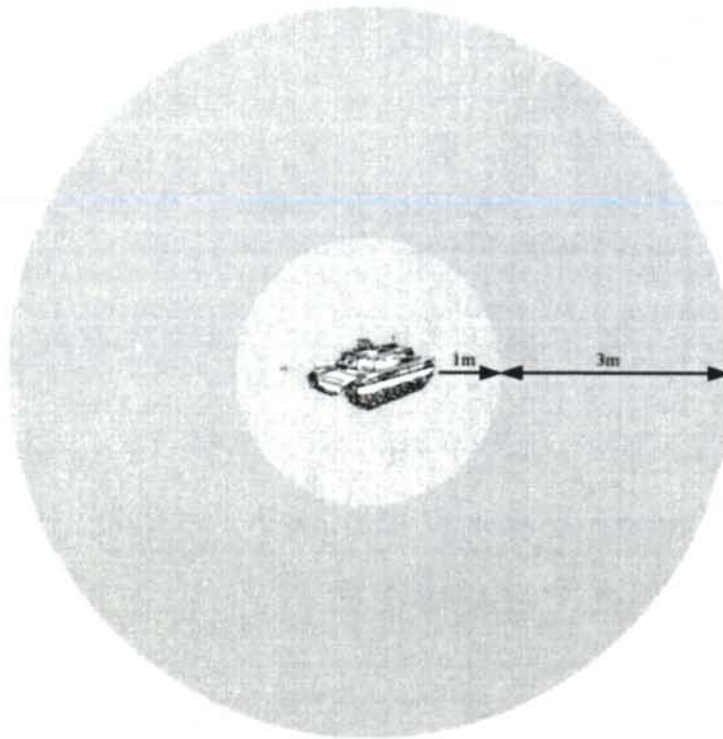


Figure 20. Sampling Pattern Around Target Tanks, WAT Range

Surface soil composite samples (30 increments) were collected around the target at 1 and 3 m

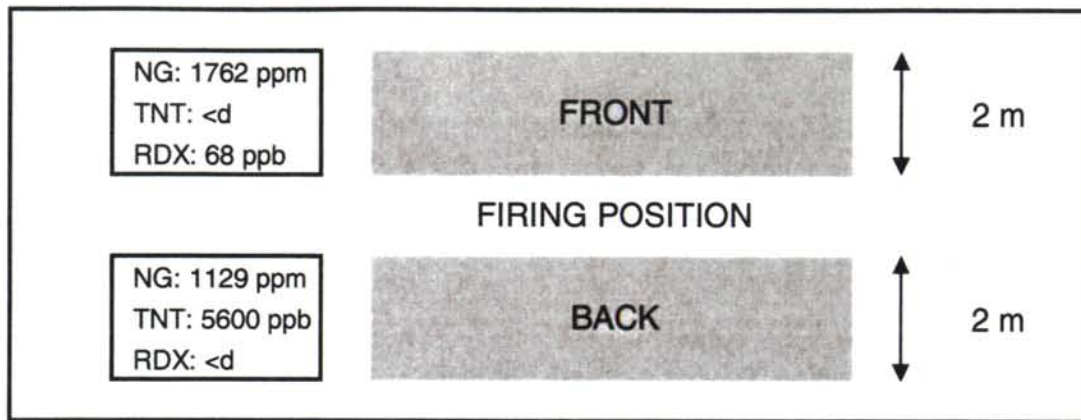


Figure 21. Firing Point Surface Sampling, WAT Range

Note: Arrows represent the distance from firing position where composite soil samples (30 increments were collected)

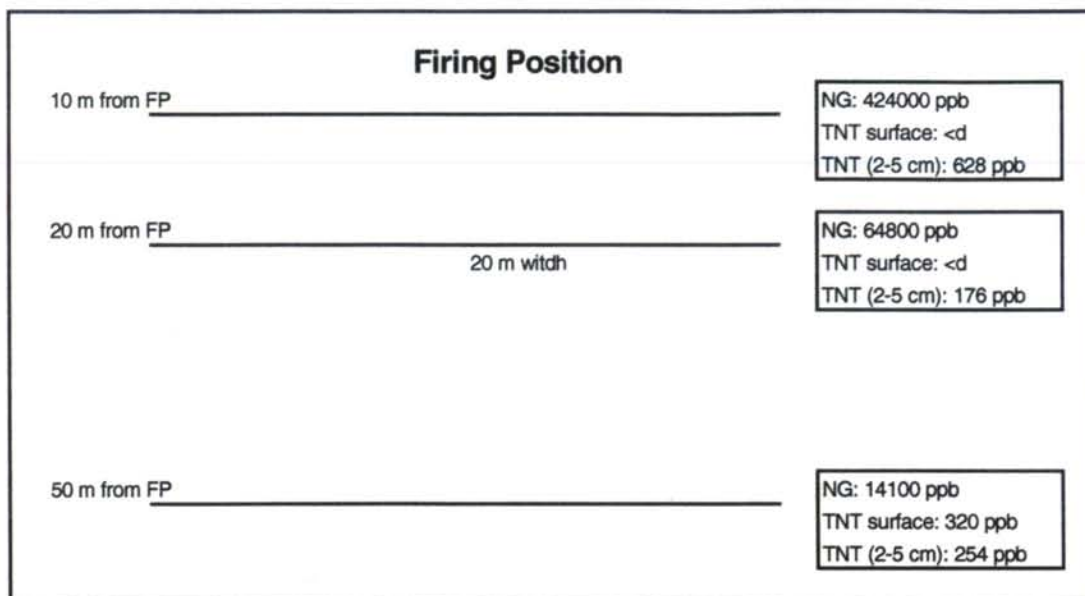


Figure 22. Firing Point Core Sampling, WAT range

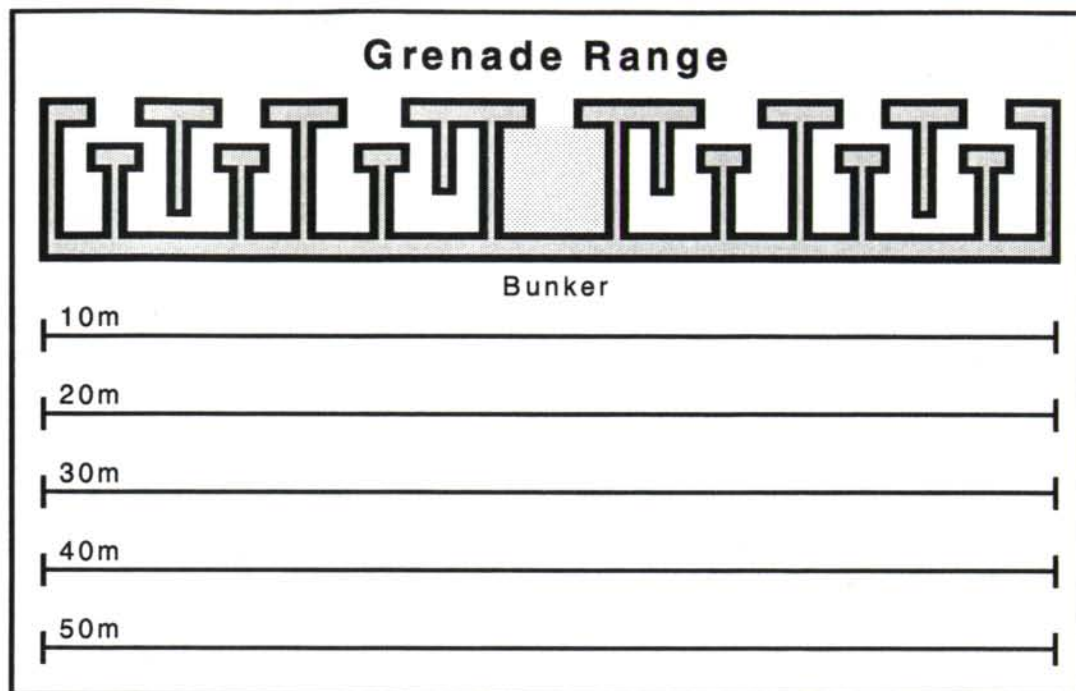


Figure 23. Linear Sampling, NCHGR Range



Figure24. Hot Spot Sampled, Lawfield Impact Area, GPS location:14016E 69427N, 105mm artillery projectile

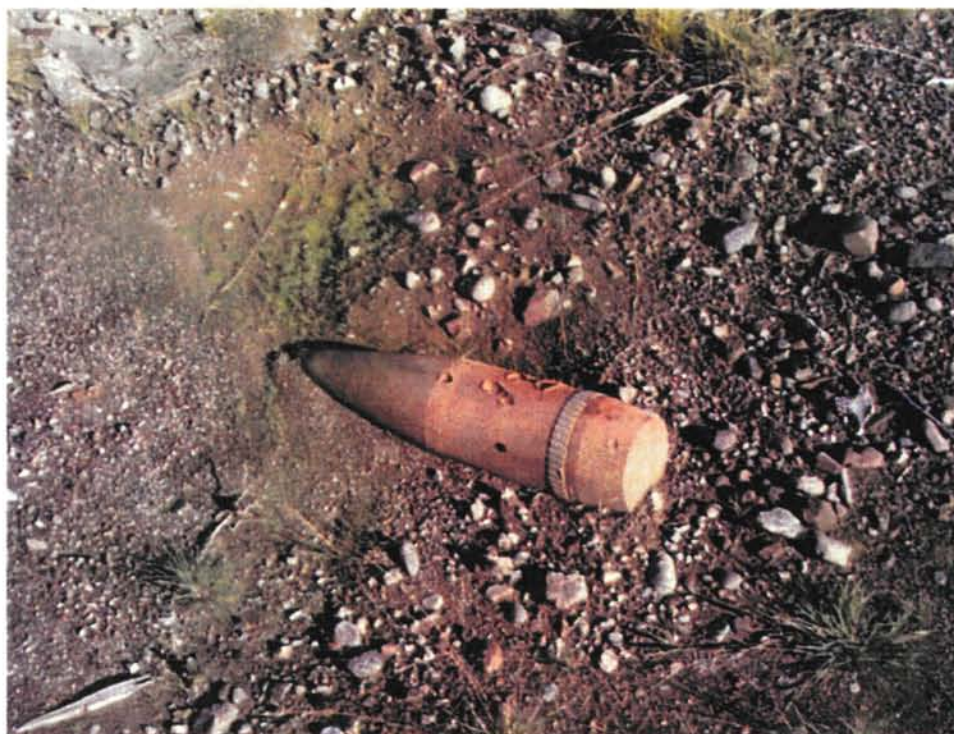


Figure 25. Hot Spot Sampled, Lawfield Impact Area, GPS location:13973E 69357N, 155 mm artillery projectile



Figure 26. Fresh Trigran Crater, AR Impact Area



Figure27. Low Order Crater, AR Impact Area



Figure 28. Biomass Collection, Pond Down-Gradient of a Highly Cratered Area, AR Impact Area

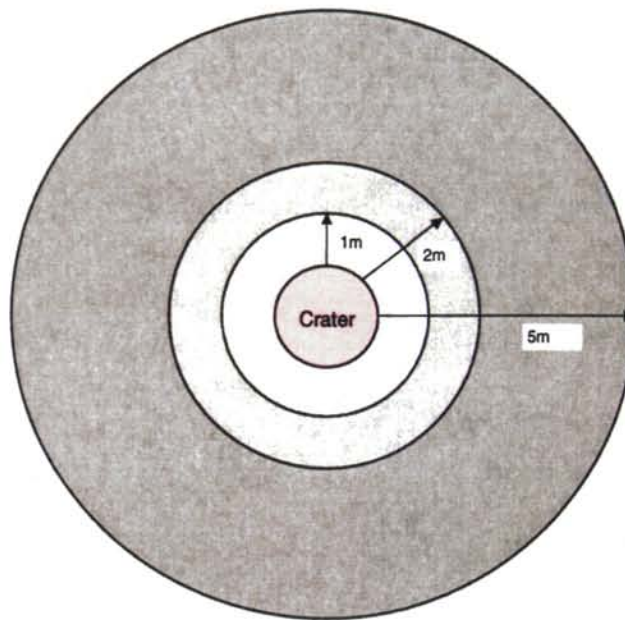


Figure 29. Circular Sampling Pattern Used Around Crater, AR Impact Area

A composite sample (30 increments) was collected around each crater at each distance indicated.

Target number											
1	2	3	4	5	6	7	8	9	10	11	12
Composite sample				Composite sample				Composite sample			

Figure 30. Sampling Pattern, Batouche and Vimy Small Arms Range

Target number																							
1	2	3	4		5	6	7	8		9	10	11	12		13	14	15	16		17	18	19	20
Composite sample				Composite sample				Composite sample				Composite sample				Composite sample							

Figure 31. Sampling Pattern, Reichwald Small Arms Range

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List of Symbols/Abbreviations/Acronyms

AA	Antiarmour Range
AR	Argus Impact Area
BG	Background Sample
CCME	Canadian Council of Ministers of Environment
CFB	Canadian Forces Base
CGR	Old Castle Grenade Range
CRREL	Cold Regions Research and Engineering Laboratory
DLE	Directorate Land Environment
DND	Department of National Defense
DNT	Dinitrotoluene
DRDC-Val	Defense Research and Development Canada
EOD	Explosive Ordnance Disposal
FP	Firing Position
GC/ECD	Gas Chromatograph/Electron Capture Detector
GF	Greenfield Impact Area
GPS	Global Positioning System
H	Hersey Impact Area
HS	Hot Spot
ICP/MS	Inductively Coupled Plasma/Mass Spectrometry
L	Lawfield Impact Area
LS	Linear Sample
NCHGR	New Castle Hand Grenade Range
NCRGR	New Castle Rifle Grenade Range
OB/OD	Open Burning/Open Detonation
QA/QC	Quality Assurance/Quality Control
S	Soil Sample
SAR	Small Arms Range
SS	Subsurface Soil Sample
TNT	Trinitrotoluene
UXO	Unexploded Ordnance
WAT	Wellington Anti Tank Range

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Troop readiness requires live fire training with various types of ammunitions. More than 99.99 % of the Canadian ammunition stockpile is used in our Country in training exercises. By better understanding the potential environmental impacts of each type of live firing activity, the Department of National Defence (DND) will be able to mitigate potential adverse effects by adapting the practices to minimize such adverse impacts. In this context, the Director Land Environment (DLE) tasked DRDC-Val to initiate a R&D program involving the environmental characterization of their main training areas to improve the knowledge on the impacts of many types of live firing training activities. DRDC-Valcartier managed the overall work and performed the surface soils and biomass studies in collaboration with Cold Regions Research and Engineering Laboratory (CRREL) scientists. The second site selected for the study was CFB Gagetown based on its intensive use by our force and allied forces and based on its geological and geographical context. In 2001, hydrogeological work was conducted in the northern half of the CFB Gagetown. This first phase involved the sampling of 42 wells to characterize the underlying groundwater flow dynamics as well as the chemical characterization of the groundwater quality. In 2002, a second phase was undertaken, including the drilling of more wells mostly in the southern half of the base and the collection of surface soils and biomass at selected locations over the entire base. This report details the surface soils and biomass characterisation of Gagetown main training ranges while a second report will be published on the hydrogeological context of the training area. Both energetic materials and metals were analysed in surface soil samples while only metals were analysed in the biomass samples. Various types of ranges were sampled including, antiarmour, antitank, grenade and rifle ranges as well as artillery impact areas. This report details the surface soils and biomass characterisation of Gagetown main training ranges. Both energetic materials and metals were analysed in surface soil samples while only metals were analysed in the biomass samples. Results obtained for metals showed the accumulation of various metal analytes in all types of ranges with higher hits in grenade and rifle ranges. Metals that showed clear accumulation pattern from the training activity were lead, strontium, cadmium, copper, zinc and aluminium. Energetic materials were detected in various soil samples in all types of ranges with the exception of the small arms ranges. The antitank range target area presented high levels of HMX and other explosives while the firing position presented detectable levels of propellant residues. Grenade ranges showed a pattern of multi-contamination by various explosives. Some hits were also recorded in the larger artillery ranges where linear composite sampling was conducted preferentially in craters. Hits were also observed near low-order events or cracked UXOs. This study was sponsored jointly by DLE and the Strategic Environmental R&D Program (SERDP) a US funding programme.

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